Integrated Framework Development
For
Intelligent Transport
Enforcement Systems

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This work or any part thereof has not previously been presented in any form to the University or to any other body whether for the purposes of assessment, publication or for any other purpose (unless otherwise indicated). Save for any express acknowledgments, references and/or bibliographies cited in the work. I confirm that the intellectual content of the work is the result of my own efforts and no other person.

Signature………………………………………..

Date……………………………………………..

Abstract

This thesis presents the Ph.D. research from the initial stages of investigation, to design and development of an intelligent architecture for vehicles. It was identified that vehicles, intelligent transport systems (ITS) and infrastructure lack a shared platform that allows them to be integrated and work together. With a robust and intelligent framework, distributed ITS can work and improve traffic efficiency. If these gaps are addressed, then they can provide reductions in cost, space and integration opportunities for enhanced functionality as well as additional services.

As a part of this research a novel framework was developed, and two ITS systems were integrated such that remote communication with the infrastructure was achieved. Evaluation of this framework indicated that information can be shared across vehicle systems and other ITS systems could be added to the network to improve performance, safety and enforcement.

To support the framework design, a Traffic Improvement Algorithm (TIA) was developed that improves traffic efficiency. This was validated using micro simulation tool that showed improvement in traffic efficiency when the algorithm was used.

When bringing new technology into the market, there are some fundamental influencing factors affecting the selection and development prior to entering the end-user market. These factors are often neglected, and the current market lacks the ability to analyse the time it would take the new technology to come into the market. As a part of this research, a toolkit was developed that helps in estimating the time the technology takes to penetrate the market.

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Dedication

This thesis is dedicated to my cousin Murtaza Khambaty and his family who died in a tragic accident on the motorway M1 June 2003. I hope that the proposed architecture and systems discussed in this thesis are developed to a usable level and brought to the market to help prevent such severe accidents.

Acknowledgements

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Finally, I would like to thank my family for their patience, encouragement and support to help me complete this thesis.

Abbreviations

ABS	Anti-lock braking system
ACC	Adaptive Cruise Control
ACK	Acknowledgement
ACL	Asynchronous Connection-Less
ADAS	Advanced Driver Assistance Systems
ADC	Analogue to digital converter
AF	Audio Frequency
AFSK	Audio Frequency Shift Keying
AHP	Analytic Hierarchy Process
AI	Artificial Intelligence
API	Application Programming Interface
ATMS	Automatic Traffic Management System
ATTMS	Advanced Travel and Traffic Management Systems
CAN	Control Area Network
CAS	Collision Avoidance Systems
CASE	Computer Aided Software Engineering
CCTV	Closed Circuit Television
CD	Carrier Detect
CDMA	Code-Division Multiple Access
CDPD	Cellular Digital Packet Data
CMOS	Complementary Metal Oxide Semiconductor
CRC	Cyclic Redundancy Check
CTS	Clear To Send
CVHS	Cooperative Vehicle Highway Systems
CVIS	Cooperative Vehicle Infrastructure Systems
CVO	Commercial Vehicle Operations
CWS	Collision Warning Systems
DAB	Digital Audio Broadcast
DbW	Drive by Wire
DCD	Data Carrier Detect
DCE	Data Communication Equipment
DETR	Department of Environment, Transport & the Regions
DFD	Dataflow Diagram
DfT	Department for Transport
DGPS	Differential GPS
DMB	Digital Multimedia Broadcast
DoT	Department of Transport
DR	Dead Reckoning

DRIVE	Dedicated Road Infrastructure for Vehicle Safety in Europe
Dll	Dynamic linked library
DSR	Data Set Ready
DSRC	Dedicated Short Range Communication
DTE	Data Terminal Equipment
DTR	Data Terminal Ready
DVB	Digital Video Broadcast
dWIM	Dynamic Weigh in Motion
ECU	Engine Control Unit
EGRS	Electronic Route Guidance System
EMS	Emergency Management Systems
EOF	End of Frame
EPS	Electronic Payment System
ETC	Electronic Toll Collection
FLS	Fuzzy Logic System
FM	Frequency Modulation
FMS	Fleet Management Systems
FOT	Field Operation Tests
FTA	Freight Transport Association
GA	Genetic Algorithm
GEO	Geostationary Earth Orbit
GFSK	Gaussian Frequency Shift Keying
GHz	Giga Hertz
GIS	Global Information Service
GNT	GSM Network Unit
GPRS	General Packet Radio Service
GPS	Global Positioning Satellite
GSM	Global System for Mobile Communication
GUI	Graphical User Interface
HA	Highways Agency
HEO	Highly Elliptical Orbits
HGV	Heavy Goods Vehicle
I2V	Infrastructure to vehicle
IC	Integrated Circuit
IDB	ITS Data Bus
IFS	Inter Frame Space
IP	Internet Protocol
ISA	Intelligent Speed Adaptation
ISO	International Standards Organization

ITS	Intelligent Transport Systems
IVC	Inter-Vehicle Communications
IVHS	Intelligent Vehicle Highway Systems
KPI	Key Performance Indicator
LCV	Light Commercial Vehicle
LEO	Lower Earth Orbit
LGV	Light Goods Vehicle
LIDAR	Light Detection and Ranging
LIN	Local Interconnect Network
LSI	Large Sale Integration
MCA	Multi Criteria Analysis
MEO	Medium Earth Orbits
MHz	Mega Hertz
MS WIM	Multiple Sensor Weigh in Motion
MTBF	Mean Time Before Failure
MTFC	Mainstream Traffic Flow Control
OBE	On-Board Equipment
OCS	Occupant Classification System
OEM	Original Equipment Manufacturer
OMG	Object Management Group
OO	Object-Oriented
OOA	Object-Oriented Analysis
OOSD	Object-Oriented System Design
OSI	Open Systems Interconnection
PC	Personal Computer
PCS	personal communications service
PROMETHEUS	Programme for European Traffic with Highest Efficiency and Unprecedented Safety
RADAR	Radio Detection and Ranging
RBDS	Radio Broadcast Data Service
RD	Receive Data
RDS	Radio Data Service
RF	Radio Frequency
RFID	Radio Frequency Identification
RG	Route Guidance
RM	Ramp Metering
RSE	Roadside Equipment
RTC	Road Tax Collection
RTR	Remote Transmission Request
RTS	Request To Send

SAE	The Society of Automotive Engineers
SCO	Simultaneous Synchronous Connection-oriented
SCOOT	Split Cycle and Offset Optimisation Technique
SMS	Short Messaging Service
SOA	Service Oriented Architecture
TCP/IP	Transmission Control Protocol/Internet Protocol
TD	Transmit Data
TDMA	Time-Division Multiple Access
TIA	Traffic Improvement Algorithm
TMC	Traffic Messaging Channel
TTB	Time-To-Break
TTC	Time-To-Collision
TTI	Traffic and Travel Information
TTCAN	Time-Triggered CAN
UART	Universal Asynchronous Receiver-Transmitter
UHF	Ultra High Frequency
UML	Unified Modelling Language
UMTS	Universal Mobile Telecommunications System
UNAT	Dearborn Electronics’ diagnostic tool
USB	Universal Serial Bus
V2V	Vehicle To Vehicle
VAN	Vehicle Area Network
VICS	Vehicle Information and Communication Systems
VII	Vehicle Infrastructure Integration
VMS	Variable Message Signs
VSC	Vehicle Simulation Component
VSCS	Vehicle Speed Control System
VSL	Vehicle Speed Limiter
V-to-V	Vehicle To Vehicle
VTS	Vessel Traffic System
WIM	Weigh in Motion
WSN	Wireless Sensor Network

Chapter 1 : Background

1.1 Introduction

Intelligent Transport Systems (ITS) have been around since the 1970s, and since then their importance and presence has increased in one's life. Luo, Q. (2008), states that recent advances in vehicle electronics have led to a move toward fewer, and more capable computer processors on a vehicle. A typical vehicle in the early 2000s housed between 20 and 100 individually networked microcontroller modules. The current trend has evolved towards fewer microprocessor modules enhanced with memory and a resident operating system. This allows more sophisticated software applications to be implemented, including model-based process control, artificial intelligence, and ubiquitous computing in a vehicle.

Integration of current and emerging technologies in fields such as information processing, communications, and electronics have paved the way for ITS to establish a stable application ground. Zelinka, T. (2008), states that adopting ITS applications in the real practice can significantly help in resolving the different transport optimization tasks significantly faster.

Riley, P. (2010), states that ITS in general had moved on from the situation 10-15 years ago, when it was still seen as an unknown quantity requiring extensive ex-post evaluation. Today ITS are becoming an increasingly mainstream element of traffic and demand management across the whole of Europe, consuming an increasing proportion of transport infrastructure investment and operations budgets. Benton, H. P. (2009) discusses that, New York City in 1988 became the first principal U.S. city to place cameras on traffic lights in an experimental attempt to catch drivers who run red lights.

Chapter 1: Background

Adell, E. (2011) discusses how newly developed in-vehicle systems based on information and communication technology offer the realisation of numerous ITS applications such as avoiding accidents related to inappropriate speed and/or distance to the vehicle ahead. Such warning systems were expected to support the driver to keep safe speed and headway in all situations by timely warning when a critical safety situation emerges.

1.2 ITS enforcement systems

Traffic enforcement can be perceived as ways or methods that assist law agencies to control and prevent traffic violations. These were introduced initially in the form of manned authorities (policemen). Nowadays, there are different types of enforcement systems that could be categorised into passive, active and intelligent enforcement systems.

Passive enforcement includes methods such as speed restriction measures, traffic signals, check points and others. Active enforcement includes amongst other use of speed cameras, traffic cameras, weigh bridges and number plate recognition etc. Intelligent enforcement takes active enforcement to another level by enhancing the applied techniques using communication technologies to control and manage traffic violations.

Eirin R. (2012) refers to a Norwegian study in the paper by Elvik, R. (2007) that compared the percentage of vehicles speeding at 34 traffic counting stations. It found that increased penalties did not decrease the problem of speeding. However, the analysis found significant differences in estimates of the amount of enforcement, between those who had seen police activities more than once along the road section and those who had never seen any enforcement activities or seen it only once. This analysis indicates that high levels of active enforcement does not result to analogous level of law abiding drivers. On the other hand, drivers who observe police surveillance activities often have a more realistic impression of the enforcement level. Tay, R. (2009) reports that while manned enforcement has a significant impact on both total and serious crashes, automated enforcement only has an effect on total crashes. The author also suggested that whereas manned enforcement provides deterrence targeted at the high-risk drivers, automated enforcement provides a general deterrence effect on a broad spectrum of the driving population.

Jones, A. (2008) states that although the UK has one of the best road safety records within the European Union, a 2007 Department for Transport (DfT) report indicates that an average of 3, 000 people are killed and over 40, 000 seriously injured every year on its roads. In a separate study, they assessed the impact of crash and casualty numbers with the introduction of mobile speed cameras in Norfolk, England. The study employed road traffic accident casualty and crash data that were collected for two years before the introduction of speed cameras at 29 sites around Norfolk. It was found that with the introduction of camera at the 29 sites, crashes decreased by 19% and fatal and serious crashes by 44%. The reduction in total crashes was significantly greater than that expected from the effect of regression to the mean in 12 out of 20 sites tested. This study indicated how basic ITS systems such as speed cameras could result in real and measurable reduction in accidents.

Joubert, J. (2011) analyses speed data from 2008 - 2009 and concluded that there was a significant overall decrease in accident rates across 12 roads equipped with enforcement speed cameras. Not only there was a reduction in number of accidents, but also a reduction in average infringement of vehicle speed in 2009 compared to 2008.

Belin, M. (2010) compares two different speed camera systems in Australia and Sweden. From the analysis, it was discovered that although both systems had the same objective (i.e. reduce speeding), the way this was achieved differed substantially.

Such studies indicate that if advanced enforcement technologies, such as Intelligent Speed Adaptation (ISA) were used, the rate of accidents would decrease dramatically, and traffic safety would increase significantly.

1.3 Benefits of ITS enforcement

During the last three decades, the use of automated traffic enforcement has mainly been applied to speed and red light violations. The increased use of enforcement technologies like digital video and image processing, dedicated short range communication, global positioning satellites applications, as well as the electronic identification of vehicles, have paved the way for extending the applications to a wider spectrum of violations, as well as making the enforcement much more efficient in the future. The advantages of two prominent enforcement systems are discussed below:

1.3.1 Intelligent Speed Adaptation (ISA)

Adell, E. (2011) have identified in the research the fact that targeting speeding drivers will bring the largest reduction in road crashes. This reduction should also be compared with the introduction of compulsory seatbelt wearing for front seat occupants which achieved a 7% reduction in fatalities overall.

Wankhede, S. (2011), addresses the concerns in road safety and discuss how systems such as ISA, can assist in solving them. A study by Carsten, O. (2001) indicates that a mandatory ISA would reduce injury accidents by 20% and fatal accidents by 37%. They further discussed that with a more advanced version of mandatory ISA, which is capable to respond to current network and weather conditions, a reduction of 36% in injury accidents and 59% in fatal accidents was possible. A cost benefit analysis carried out showed that benefit-cost ratios for this implementation strategy were in a range from 7.9 to 15.4.

1.3.2 Dynamic Weigh in Motion

Perrett K.E. (1996) states that the implementation of dWIM application will be driven, if at all, by public sector considerations of the costs and benefits. By applying sensitivity analysis, it is identified that a 10% reduction in motorway maintenance cost in a year could be realised if Dynamic Weigh in Motion (dWIM) is introduced. If overloading is controlled, then road wear and tear related to overloading would also decrease. This reduction of road wear and tear, associated with overloaded Heavy Good Vehicles (HGV), would also reduce the number of accidents.

1.4 Systems Integration

Applying systems integration leverages how independent architectures operate, either with a single system or together with other systems.

Frank, E. (2008) discusses how systems within the automotive industry are increasingly distributed and complex. This has resulted in reduced time-to-market, cost and safety concerns and demand advance validation of the integrated systems and its components, from the functional, timing, and reliability standpoints.

As a part of the vehicle architecture, there are various functionalities implemented through Electronic Control Units (ECU). This increases the proliferation in the number of ECUs, subsystems and network buses, and the increasing interdependency of functions makes these systems difficult to test and validate. Currently vehicles are moving from a standalone ECU mode to a networked multiple ECU architecture. Frank, E. (2008), discusses how these advances in technology and engineering, demand a strong requirement for system integration.

Currently enforcement technologies like speed cameras, weigh bridges and road side speed indicators can only make people aware of traffic offences that have been committed. However, the limitations of these technologies lack control for preventing such traffic violations. Such limitation of passive enforcement systems can be overcome using active enforcement systems such as ISA, automatic vehicle identification and dWIM.

1.5 Importance of system integration

Successful integration of systems between suppliers and Original Equipment Manufacturers (OEM) will lead to greater efficiency and better services. In order to achieve this level of integration, a comprehensive planning and use of a proven methodology is required. Moreover, the methodology may focus on the use of technology to provide solutions to the business requirements, not on the technology itself. The goal is to gain a competitive advantage in each industrial line in the most efficient manner.

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Kraus, E. (2003) indicates that similar advances have been made in traffic enforcement technologies. Active systems such as speed cameras, detectors, weigh bridges, etc, have been used to control traffic lights speed and weight violations. These automated enforcement systems in European countries have a longer history than in the U.S. The problems and issues faced by U.S. in terms of jurisdiction and technologies are similar to what European countries had faced.

Frank, E. (2008) discusses the importance of standards in the software and hardware domains when optimizing automotive electronics system design which can allow plug-and play of subsystems. This ability to integrate subsystems can then become a unique product that can be used by all OEMs. This will give the OEMs a competitive advantage and increase the dependency on the novel and compelling functionalities.

In a separate paper, Di Natale, M. (2010) discusses how cost pressure, flexibility, extensibility and the need for coping with increased functional complexity are changing the fundamental paradigms for the definition of automotive and aeronautics architectures.

In both the U.S. and Europe, there has been a gradual increase in traffic enforcement technologies. Passive enforcement has been implemented at the same time as speed cameras, red light violation detectors, advanced weigh bridges. These technologies have been reviewed independently by many researches as discussed in Section 2.5. However, most of the research concentrates on independent systems evaluation and development as the technologies are still at infancy stage. A gap exists within systems integration of active ITS enforcement systems. This gap was identified, and a methodology to fill this gap is discussed in this thesis.

Chapter 1: Background

There are a number of reviews discussed in chapter 2 that evaluate and analyse the implementation of enforcement systems such as ISA and dWIM. However, there is no analysis of such systems integrated to the infrastructure thus working together as one complete framework. System integration of active enforcement (ISA and dWIM) can not only provide a better law enforcing solution but also indicate the prospects to introduce efficient integration of other traffic management solutions.

1.6 Systems integration for automotive applications

There are a number of ITS systems installed on vehicles nowadays. Some of these systems have a user interface for the driver and some operate in the background. The count for these systems is high as they are not application specific but rather vehicle manufacturer or system supplier specific. These systems have the capability to operate independently as a node or together when networked.

System-level benefits due to in-vehicle networking, many of which are only beginning to be realised. For example, a decreased number of dedicated wires is required for each function and thus reduces the size of the wiring harness. In that way, system cost, weight, reliability, serviceability, and installation are improved. Common sensor data, such as vehicle speed and engine temperature are available on the network, so data can be shared, thus eliminating the need for redundant sensors.

One of the key benefits of networking is the ability to add functions without adding new hardware or decreasing reliability. As the networking capability becomes common on mid and low-priced automobiles, the car manufacturers are able to, easily offer, functionality found only on high-end vehicles.

With the growing demand for greater safety, comfort, convenience and compliance requirements for improved pollution control, safety, convenience and reduced fuel consumption, the automotive industry has developed a multitude of electronic systems (e.g. ABS, EMS, traction control, airbags, central door locking, powered seat…). The complexity of these control systems and the need to exchange data amongst them require more and more hard-wired, dedicated signal lines.

Controller Area Networks (CAN) are cost effective to design and implement, they are easy to configure, modify and automatically detect data transmission errors. With many such advantages there have been many associated specifications like CANopen, DeviceNet, and J1939 that are enhancements to the original CAN standard. J1939 protocol is also based on the CAN standard, and it gives the flexibility to modify, enhance and implement for other applications. These protocols assist in bringing systems closer and work together.

1.7 Thesis outline

This section presents the layout and illustrates the content of the different chapters of the thesis.

In ***Chapter 2,*** a review of relevant ITS projects is presented. This incorporates discussion on the importance of ITS, findings from completed ITS projects and references to safety and communications systems used in speed limiting and weigh-in-motion applications. In this chapter, reviews on existing traffic management, the influences of ITS on various traffic management methodologies are also discussed. There are several factors that influence the launch of a new technology. It is these factors that determine the time it takes for this technology to come into the market. Detailed review of these factors is included in this chapter. The chapter concludes with the discussion on the importance on systems integration, which form the bases for this research.

Chapter 3 describes the conceptual ITS integrated framework that was developed as part of the research. In this chapter, the conceptual framework is defined using ITS systems and other components to achieve a harmonised system integration. In this chapter, the complete vehicle-infrastructure in architecture is divided into three components, in-vehicle systems, vehicle-to-base communication and base-network.

The conceptual framework is put into practice by replacing various elements of the framework with ITS systems. In-vehicle prototypes, communication technologies, simulator design and the final integrated system are described in this chapter.

Chapter 4 details the steps taken to evaluate and validate the various components in the conceptual framework described in chapter 3. Validation is done in 3 steps:

- Simulation
- Laboratory
- Real time evaluation

Chapter 5 presents a novel algorithm design and simulation tools, a TIA which is used to emphasise and validate the benefits of the proposed integrated framework.

Chapter 6 describes and discusses the time-to-market toolkit designed as a part of this research. This chapter also discusses results and analysis obtained from the questionnaire and the model that was used to identify (and predict) the time a technology would take to enter the market.

Chapter 7 concludes the thesis with a discussion of the contributions of this research to existing knowledge. to ITS. The future research activities are described with directions and suggestions that can help in improving the existing systems with a real time model.

1.8 Summary

In this chapter, a brief history of enforcement systems is presented. The chapter discusses the benefits of enforcement systems and the research aim. The main intention of this research is to lay a methodology for ITS developers to enable independent integration of systems into a vehicle, which can be monitored and controlled remotely.

Chapter 2 : Literature Review

2.1 Introduction

Advances in information technology, communications, and electronics are revolutionising all aspects of the modern-day world, homes, offices, schools and how leisurely times are spent. Likewise, information technology is changing the way transportation services are being provided across the world, in urban areas, and in rural communities. Navet, N. (2008) states that there has been an exponential increase in computer based functions embedded in vehicles. There are over 2500 signals exchanged through up to 70 electronic control units on 5 different networks in a vehicle. This makes it difficult for technologies to roll out, due to the complexity in communication design and interoperability.

Linjing L. (2010), has referred to ITS as a means of utilising synergistic technologies and system engineering methods to develop and improve transportation systems. ITS have a wide range of applications, such as increasing transportation safety (e.g., speed control) and convenience (e.g., automatic driving), improving transportation efficiency (e.g., reducing congestions), and making environmentally friendly transportation solutions (e.g., fuel consumption reduction). In the recent years, there has been significant developments in ITS from academia and industry. Papadimitratos, P. (2009), states that vehicles will carry computing and communication platforms, and will have enhanced sensing capabilities. They will enable new, versatile systems that enhance transportation safety and efficiency and will provide infotainment. Ambak, K. (2009), mentions examples of advanced driver assistance systems such as intelligent speed adaptation, driver monitoring system, collision warning and avoidance system, lane keeping and lane-change warning system, visibility enhancing system and seat belt reminder system for vehicles.

Jansson, J. (2008) describes applications of collision avoidance technologies for most transportation systems ranging from autonomous robots and vehicles to aircraft, cars and ships. In their research, they have presented a probabilistic framework for designing and analyzing existing collision avoidance algorithms proposed in literature, enabling on-line computation of the risk for faulty intervention and consequence of different actions based on Monte Carlo techniques. Shokri, F. (2009) discusses a navigation system based on the concept of fuel-economy (minimal energy consumption) that can provide travellers' the shortest travel time/distance. The system is constructed from data collected with Closed Circuit Television (CCTV) and on the platform of Visual Basic.NET. Both these papers illustrate advantages of ITS systems their importance on working as an integrated system.

2.2 Intelligent Transport Systems (ITS)

Shah, A. (2007) introduces ITS as the state-of-the-art approaches based on information, communication and satellite technologies in mitigating traffic congestion, enhancing safety, and improving the quality of the environment. ITS are combined with the individual entities that are related with the mobility such as physical infrastructure, vehicles, and controlling agencies. They include numerous products and services such as intermodal transportation systems, intelligent traffic control systems, in-vehicle technologies, safety enhancement technologies, traveller advisory systems, etc. ITS provides technologies that deal with traffic congestion and improve road safety through intelligent traffic management.

Chapter 2: Literature Review

Wang, Fei-Yue (2010) states that the subject of ITS goes back to the last three decades, and has seen initiation, development, deployment, and tremendous growth, which has had a significant impact on life and society. Papadimitratos, P. (2009) states that the recent technological developments, notably in mobile computing, wireless communication, and remote sensing, are pushing ITS a significant leap forward.

The importance of ITS is realised with the increasing safety issues, Palin, R. (2010), refers to figures from the UK Department of Transport (UK DoT) 2008 report, in which the number of people killed due to road casualties in Great Britain are 2, 538, and the total number of road accidents reported to the police are 170, 591. The total number of deaths for car users was 1, 257 with 11, 535 car users seriously injured. Fortunately, the overall trend for Great Britain is one of continual reduction and has been since 1990. The 2008 European Road Statistics indicate the overall trend within Europe as downward. In 2006, the total number of road fatalities for the 27 European countries was approximately 43, 000. The UK DoT (UK Department of Transport, 2009) reports valued the U.K. government spend to be £17.9bn towards prevention of all road accidents in 2008. In the previous UK Department of Transport, 2006 report that exceeding the limit was a contributory factor in 5% of all casualty crashes (14% of all fatal crashes), and that speeding was a contributory factor in 11% of all casualty crashes (18% of all fatal crashes).

Martinez, F.J. (2010) discusses in their paper the shift of focus from building efficient highways and roads to mechanical and automotive engineering, in pursuit of building faster cars to surmount greater distances. This then had an impact on the technology within the design and development of cars consisting of embedded sensors and advanced electronics, thus making cars more intelligent and safe to drive. With such innovations made so far in wireless communications and networking, technologies have started to impact cars, roads, and highways. It created a substantial economic, social, and global impact through the transformation over the next period of 10–15 years. Hence, technologies in the various fields have now found common grounds in the broad spectrum of Next Generation ITS.

ITS represent an enormous change in surface transportation. The automotive and transportation authorities across the world should recognize and build on the advanced technologies and systematic thinking about transportation services. There are expanded possibilities for relevant policy initiatives in technology enabled transportation that create vital professional opportunities. The electronic linkage between vehicle and infrastructure represented by ITS has profound implications for surface transportation and these changes so far have been largely incremental.

2.3 Applications of ITS

The value and benefits that ITS has brought has been recognised, and this has led to several projects and research efforts to be conducted worldwide to address road safety, vehicular communication networks, and telematics. There are several ITS initiatives and projects at different levels across the globe, and these are summarised below:

2.3.1 ITS Initiatives worldwide

2.3.1.a ITS initiatives in Japan

The main responsible authority within the Japanese government that decides on policies in ITS is the Japanese Ministry of Land, Infrastructure and Transport (MLIT).

They identified nine specific areas of developments: (a) navigation systems, (b) electronic toll collection (ETC) systems, (c) assistance for safe driving, (d) optimization of traffic management, (e) efficiency in road management, (f) support for public transport, (g) efficiency in commercial vehicles, (h) support for pedestrians, and (i) support for emergency vehicle operations. Tsugawa, S. (2011) discusses that in order to provide solutions to the issues of accidents as well as congestion, ITS projects have been conducted since mid 1980s in Japan. Recently a project VICS (Vehicle Information and Communication Systems), which is a driver information system based on road-to-vehicle communications, and ETC (Electronic Toll Collection) based on 5.8 GHz DSRC (Dedicated Short Range Communication) is well widespread and at a stage of practical use. The cumulative shipping numbers of the car navigation systems and VICS onboard units were 44 million and 30 million respectively by March of 2011. The cumulative installation number of ETC onboard units is 43 million including 8.8 million reinstallation by June of 2011, and the use rate of ETC was 87 % in June of 2011.

Smartway is another initiative together with vehicle-highway that was developed on the basis of Japan's deployment of ITS experience in 2010. Japan began widespread national Smartway deployment in 2010. Using 5.8 GHz DSRC technology, Smartway can provide visual information of road conditions ahead to the driver with location specific traffic information through an audio / visual format. Smartway can warn drivers when they approach an accident prone area of a roadway, and using DSRC-enabled roadside unit the system can alert drivers on the main lanes of the presence of merging vehicles by sending appropriate warnings.

2.3.1.b *ITS initiatives in the USA*

The start of ITS in the USA was with Electronic Route Guidance System (EGRS) in 1970s. Since then, USA in order to improve the safety and efficiency of the nation's road transportation system, together with the federal and state departments of transportation (DoTs) cooperated with vehicle manufacturers to support various ITS projects. Martinez, F.J. (2010) states that, in the USA, there are two key programs sponsored by the US DoT (Department of Transportation). The first one is the Vehicle Safety Communication (VSC) project. The second one is related to Vehicle Infrastructure Integration (VII). Weigle, M. (2008), states that the VII provides a communications link between vehicles on the road (via Onboard-Board Equipment, OBE), and also between vehicles and the roadside infrastructure (via Roadside Equipment, RSE). Applications of such communication links include mobile internet access in moving vehicles. Vehicle Infrastructure Integration (VII) connects vehicles and infrastructure and creates an “enabling communication infrastructure”.

Sheng-hai, A. (2011) states the ITS Strategic Research Plan, 2010-2014, was promulgated by the United States Department of Transportation (USDOT) on December 8, 2009. This plan defines the strategic direction for the USDOT's ITS research program for the next five years.

2.3.1.c *ITS initiatives in the Europe*

There are a number of ITS projects funded by the European Commission that aim for improvements on road safety by increasing the EU market penetration of Advanced Driver Assistance Systems (ADAS), that is currently limited by performance and cost of sensor technologies. Most of these ITS projects cover a wide spectrum, including driver-vehicle interface, emergency rescue, preventive road safety, onboard sensors, pedestrian detection, intersection safety, cooperative systems and cooperative networks, maps and geographical technologies, and vehicle-to-vehicle (V2V) communications.

In 1985, Eureka (European Road Transport Telemetric Implementation Coordination Organization) was established to promote the cooperation of government and private organization in research and development of ITS. In the following year, PROMETHEUS (Programme for European Traffic with Highest Efficiency 333 and Unprecedented Safety) was launched, but the program started officially in 1987 with a period of 7 years. DRIVE (Dedicated Road Infrastructure for Vehicle Safety in Europe) as the second phase of Europe's R & D part of the framework was adopted in June 1988. In 1991, after the successful implementation of DRIVE, the EU set up Ertico, a non-profit cooperative organization in Europe with the cooperation between government and private enterprises.

In recent years, ERTICO uses CVIS (Cooperative Vehicle Infrastructure Systems), COOPERS (Cooperative Systems for Intelligent Road Safety) and other wireless communication systems to implement the exchange of information between road infrastructure and vehicles to improve traffic safety and efficiency.

DRIVE is not in itself a complete solution but needs a follow-up with industry and public authorities. Final project reports suggest that future Research and Development actions in the field of Transport Telematics should explore their extension to the entire Transport System.

With CVIS, drivers can influence the traffic control system directly, and get individual guidance along the quickest route to their destination. Speed limit and other road sign information, weather alerts, warnings of approaching emergency vehicles, and other urgent messages will be sent wirelessly to the vehicle and displayed to the driver. Emergency personnel will reach accidents faster, while traffic will be diverted away from an incident area. With CVIS technology, hazardous goods shipments can be tracked at all times and have priority along a preselected safe route.

Toulminet, G. (2008) discusses COOPERS' vision, where vehicles are connected via continuous wireless communication with the road infrastructure. COOPERS provides vehicles and drivers with real time local situation based information and safety related traffic and infrastructure status information, distributed via dedicated Infrastructure to Vehicle Communication link (I2V).

2.3.2 Enforcement Systems

Williams, B. (2008) discusses how ITS can be employed for enforcement applications. Using ITS data from sensors and cameras (and other ITS equipped vehicles), a centralised management of violations can be achieved. Examples include: Access control, Weight control, High occupancy vehicle facility, parking regulation enforcement, speed limit enforcement, signal enforcement and emissions violation. Of the existing various enforcement ITS systems, two systems such as Intelligent Speed Adaptation (ISA) and weigh in motion (WIM) are looked in detail for this research.

2.3.2.a *Intelligent Speed Adaptation*

Speed limit enforcement can be achieved using ITS systems such as Intelligent Speed Adaptation (ISA). Intelligent Speed Adaptation (ISA) is defined as any system that constantly monitors vehicle speed, with respect to the local road speed limit and applying it with an action when the vehicle is detected to be exceeding the speed limit. Marchau, V. (2010) discuses the importance of speed enforcement stating that speed management is a central theme in traffic management, aiming to optimise traffic in terms of safety, efficiency and effects on the environment. TR, B. (1998) have found that, in about 30% of fatal road accidents, excessive speed is involved, making speed a crucial factor in road safety. Lai, F. (2012) refers to a useful review of the literature and examinations on the subject done by researchers that indicated the relationship between changes in speed and speed limits and the consequent changes in accident numbers. They concluded that there was a substantial support for a relationship in which a 1 km/h change in traffic speed led to a 3% change in the number of accidents on that road.

Types of ISA

Intelligent speed adaptation (ISA) is one of the most promising ADAS, aimed at reducing excessive speed. ISA uses an intelligent in-vehicle device that warns the driver about speeding, discourages the driver from speeding, and/ or prevents the driver from exceeding the speed limit. Karthikeyan, B. (2010) states that there are a number of Speed Adaptation systems researched and proposed, but they are not effective and result in failures. There are four main types of ISA technologies being research, some more than others.

Radio beacons: This technology uses beacons that transmit the local road speed data to a receiver in the vehicle. The transmitters send out speed data, which is received by the in-vehicle receiver when it is in the range of the transmitter and vehicle speed is adjusted depending on the speed limit data received.

Optical recognition systems: This technology uses image recognition through vehicle mounted cameras that continuously capture images of the road. The images are processed to detect any speed information available from road signs. Once this information is obtained the algorithm classifies the digits on the sign (using image recognition) which can then be used to adjust the speed of the vehicle.

Dead reckoning: This type of ISA system use a mechanical system linked to the vehicle's driving assembly in order to predict the path taken by the vehicle. This is done by measuring the wheel rotation and vehicle orientation over time, thus estimating the vehicle's speed and distance. Dead reckoning requires the vehicle to start at a fixed point. Using speed and distance data along with other factors such as steering wheel angle, sensorics (accelerometers, gyros) the vehicle path can be compared with a digital map to determine its local speed limit.

GPS based systems: Most ISA systems use global positioning system (GPS) and a digital speed limit database. The position of the vehicle is determined using a GPS receiver and is used to retrieve the speed limit or other information from a database. The information is then used to present the current speed limit for that location.

Based on this information Marchau, V. (2010), suggests that different feedback strategies can be used: (i) informing ISA displays the speed limit and reminds the driver of speed limit changes, (ii) warning ISA gives a visual or auditory non-committal warning when the driver exceeds the limit, (iii) intervening ISA gives a counterforce on the gas pedal when the driver tries to exceed the speed limit and (iv) controlling ISA automatically limits the maximum speed of the vehicle to the speed limit. A similar approach was suggested also by Carsten, O. (2005) by which ISA-devices can be categorised into different types depending on how much they interfere in the vehicle-driving task.

Effects of ISA

Marchau, V. (2010) states that the effects of ISA on speed cannot easily be translated into effects on traffic safety, the environment and traffic efficiency. This is due to the lack of theoretical knowledge on the exact relationship(s) between (microscopic) vehicle speed behaviour and (macroscopic) traffic flow behaviours. Secondly, the experimental conditions in the consulted studies differ in terms of their scale and the extent to which they represent real traffic. Finally, the different types of effects are often described separately, but they are also related. For example, fewer crashes could cause a reduction in congestion, which in turn has a beneficial effect on the environment. An overview of ISA effects on mean speed, standard deviation of speed and speed violations in various studies worldwide is summarised in the Table 2-1. Based on an extensive overview of studies it was concluded that ISA has a positive effect on speeding. In relation, the effects of ISA on traffic safety and the environment are also positive. The effects on traffic efficiency on the whole seemed to be neutral. However, all these results depend on which kind of ISA is studied, and the assumed percentage of vehicles equipped with ISA.

Methodology	Country	ISA type	Effect on mean speed	Effect on speed variance	Effect on speed violations
simulator	FIN	controlling	↑	↓	?
simulator	UK	informing, controlling	↓	↓	?
simulator	NL	intervening	↓	↓	↓
instrumented vehicle	NL	warning	↓	↓	↓
instrumented vehicle	FIN	informing, warning, controlling	↓	?	↓
instrumented vehicle	NL	warning	?	?	↓
FOT	NL	controlling	↓	↓	?
FOT	DK	warning	↓	?	?
FOT	S	warning, intervening	↓	↓	↓
FOT	B	intervening	↓	↓	↓
FOT	AUS	intervening	↓	↓	↓

(↓- decrease, ↑- increase, ?- not investigated) FOT = Field Operation Tests

Table 2-1: Overview of ISA effects

2.3.2.b Weigh-in-motion System

Weigh-in-motion or Weighing-in-Motion (WIM) devices are designed to capture and record axle weights and gross vehicle weights as vehicles drive over a measurement site. Unlike older static weigh stations, current WIM systems are capable of measuring at normal traffic speeds and do not require the vehicle to stop or drive at low speed, making them much more efficient. Wang, Z. (2009) discusses that there are two main ways for implementing WIM. The more popular employs dynamic axle load weighing, in which weight is measured on every axle, and the weight of the vehicle is calculated by the testing system. However, due to constraints, such as the short time the tyre lies on the weighing table, the force in the weighing table, speed, vehicle self-resonance and road surface, achieving precise results is quite difficult.

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Figure 2-1 shows how heavy vehicles are weighed on static scales at low-speed using weigh-in-motion scales at weighing stations. Vehicles are driven over these scales at a speed of up to 15 km/h, or on portable weighing pads, which are placed under the tyres of the truck. Low-speed weighing stations are rather expensive to setup and to maintain. On the other hand, high-speed WIM systems provide continuous unbiased weighing of practically all vehicles passing the system. They are also imperceptible which means that the drivers are not aware of the weighing operation and do not try to avoid it.

Figure 2-1: Static scales

Guofeng, Z. (2010) developed a multiple sensor (MS-WIM) system which has sensors installed in the road surface by maintaining the surface between MS-WIM sensors and the load bed at the same horizontal level. When the vehicles are driven over the surface, the sensors detect the weight signals. With the help of measuring circuits, the sensor data is collected and converted from an analogue to a digital signal before transferring it to the host Personal Computer (PC) for analysis. The static axle load is calculated upon data conditioning at the host computer which results in the real weight of the vehicle. This setup has its limitations due to factors associated with the vehicles. This include vehicle's axle load, vehicle's vibration, vehicle's speed, tyre pressure and section width. Other factors, not associated with vehicles which need to be taken into consideration include sensor's sensitivity, road surface flatness and ambient temperature.

Bernard, J. (2010) discusses the different types of WIM systems. Early WIM systems such as bending & load cell plates and strip sensors were reviewed and compared to recent ones such as multiple sensors (MS-WIM). Multiple sensors WIM (MS-WIM) consists of several road sensors installed at uniform or non-uniform spacing along a road section of 10 to 50m. For a given axle, each sensor will measure the axle load (or force), which varies with time and distance. The axle is bouncing along the road slightly, although liftoffs rarely occurs on extremely rough roads. The sensor array allows for the multiple measurement of the wheel load. There are some design and implementation issues with MS-WIM systems such as individual sensor accuracy for axle force measurement and sensor calibration. Additionally, the sensor response needs to be stable and independent of the environment. Weighing trucks using on board equipment (OBE), was realised in the 1980s and '90s with instrumented vehicles. Most of these systems used accelerometers and strain gauges mounted on the vehicle body (suspended masses) and/or on the axles, or wheels (non suspended masses). The impact forces were calculated using calibrated vehicle dynamic models. However, this kind of WIM required rather complex calculations, used expensive instrumentation and the dynamic calibration of the systems needed sophisticated testing platforms, trained staff, and a considerable amount of time.

Advantages of OBE WIM over other WIM applications include mobility for measurement, which means that sensors can be installed on the vehicle rather than on the road. Installation and maintenance costs for axle strain sensors are significantly lower than weigh bridges.

Guo, L. (2004) developed a software model and algorithms to analyse data that was acquired from an axle based WIM system using piezoelectric sensors. The algorithms helped to obtain accurate measurements with speed corrections (algorithm). They also concluded that the use of multiple sensors increases the measurement accuracy since it reduces the effects of vehicle dynamics.

2.3.3 Safety Systems

There are a number of other ITS safety systems that were reviewed to indicate the importance and necessity of systems integration for ITS.

2.3.3.a Collision Warning System

A collision warning system is a safety ITS system designed to reduce the severity of an accident. This system uses various types of sensors such as radar, laser, and others to detect an imminent crash. Depending on the design, the system may warn the driver, mitigate the crash by braking, reposition the passenger seat and/or head rests or tension seat belts to minimise the impact.

Zhu, H. (2010) discusses how advances in wireless communication technologies has enabled vehicles on a highway to communicate and share state information and provide drivers with potential collision warnings. Sehun, K. (2011) describes a GPS based vehicle collision warning system that detects a potential car crash in advance and warns the danger to drivers.

Enhancements to CWS can be done by considering road conditions to improve system perception, thus adding the ability to identify hazard situation in the night or curved roads. Rong, H. (2010) proposes a system where vehicle illumination and night visibility is enhanced considerably. The perception and forward collision warning system (PFWS) discussed in their paper propose integrated Adaptive Front-lighting System and safety warning systems to enlarge the field of driver's vision, enhance the capability of road condition perception and improve the safety. At the same time, PFWS also has a network interface (CAN / LIN bus), through which information from sensors and warning signal can be shared with other systems on the vehicle. Thereby the degree of system integration improved considerably.

2.3.3.b *<u>Vehicle Location and Navigation Systems</u>*

Automatic Vehicle Location systems (sometimes referred to as Automatic Vehicle Monitoring or Automatic Vehicle Location and Control systems) are computer based vehicle tracking systems. Aloquili, O. (2009) states how tracking system technology was made possible by the integration of three new technologies: navigational technologies such as global positioning system (GPS), database technologies such as geographic information system (GIS) and communication technology such as general packet radio service (GPRS).

Skog, I. (2009) states the numerous applications that these navigation aids are designed to support the driver by showing the vehicle's current location on a map and by giving both visual and audio information on how to get from one location to another, efficiently i.e., route guidance. Further applications include vehicles used in professional services such as taxis, buses, ambulances, police cars, and fire trucks, which are equipped with navigation systems that not only show the current location but constantly communicate the vehicle location to a monitoring centre as well. They are used for applications such as accident reporting, navigational services, automated billing, fraud detection, roadside assistance, and cargo tracking. These applications have also led this technology to be further used for several types of real-time information with benefits for commercial vehicle operations.

With recent advances in wireless communications and low power electronics, accurate position location may now be accomplished by a number of techniques that involve commercial wireless services. Emerging position location systems, when used in conjunction with mobile communications services, can lead to enhanced public safety and revolutionary products and services.

2.3.3.c Fleet Management System

A Fleet Management System (FMS), is used for logistics-nature applications, although some functionality (e.g. monitoring) can be characterized as safety oriented. A FMS is used by many companies that need to monitor their drivers and vehicles in order to reduce costs and improve service. Accurate knowledge of the vehicle's position at any time increases driver and vehicle's safety. A fleet management system integrates informatics and positioning technology to monitor the status of each vehicle in the fleet at all times.

Chadil, N. (2008) proposes a real-time tracking management system composed of three components, a Global Positioning System (GPS) Tracking Device, a server and a database. The GPS tracking device is an embedded system that transmits location information to the server through General Packet Radio System (GPRS) communication network. The server receives the information and stores it in the database. Based on this information the vehicle location is displayed using Google Earth or Google Map software.

2.4 ITS Architecture

The aim of ITS is to offer benefit from improved safety, reduced traffic congestion, and more environmentally friendly driving, through their wide variety of applications. Kosch, T. (2009) states that the key to achieving these benefits lies in a common and standardized means of communication between the various components of such systems, whether these components are located in vehicles, at the roadside, or in the back-end infrastructure. Therefore, ITS architecture comprises four main entities: vehicles, roadside equipment, central equipment, and personal devices. Depending on the deployment scenario, the four entities can be composed arbitrarily to form a cooperative ITS.

2.5 ITS Communication Technologies

The developments in communication technologies for ITS has become one of the key means to encourage the development of safety and efficiency of the increasingly overloaded road infrastructure. Böhm, M. (2008) discusses the most recent development, which is the implementation of cooperative traffic management systems, using wireless infrastructure-to-vehicle (I2V) data-communication link for the transmission of safety critical messages into the vehicle.

Papadimitratos, P. (2009) discusses how vehicles have become sophisticated computing systems, with several computers and sensors onboard, each dedicated to one part of the car operation. Additionally with new wireless communication, computing and sensing capabilities, interconnected vehicles not only collect information about themselves and their environment, but they also exchange this information in real time with other nearby (in principle) vehicles.

Wireless communication is a broad and rapidly expanding field. The ITS architecture is most concerned with wireless *data* communication. The combination of breadth of communication system possibilities, new technology and proprietary systems, makes the analysis effort a rather daunting task. Wide area communication systems are applicable to ITS systems that interact with the infrastructure at a broader network range.

The application of the communication technologies in ITS, lies within the vehicle, vehicle to vehicle (V2V) and vehicle-to-infrastructure (V2I). Typically, wired for in-vehicle communication and wireless for a vehicle to vehicle and a vehicle to infrastructure applications. Uses of different technologies vary with the requirement and different characteristics (bit rates, communication range, transmission power, frequency bands). At a basic level, there are short-range ad hoc communication options primarily for V2V and some V2I communication, but mainly for V2I ITS applications long-range infrastructure-based communication is used.

Kosch, T. (2009) summarises the current wireless systems that are used for ITS applications:

- Short-range and ad hoc systems — This includes European Committee for Standardization dedicated short range communications (CEN DSRC), European 5.9-GHz ITS, wireless LAN (WLAN), and Infrared. Peytchev, E. (2006) states that vehicles are considered a prime area for the deployment of ad hoc networks and several projects are currently investigating a number of application areas, including traffic and travel information systems. In existing ad hoc ITS implementations, traffic information is obtained from sensors data transmitted by individual vehicles.

- Cellular systems — This includes WiFi, worldwide interoperability for microwave access (WiMAX), global system for mobile communications/general packet radio service (GSM/GPRS), and the universal mobile telecommunications system (UMTS).
- Digital broadcast systems — This includes digital audio broadcasting (DAB) and digital multimedia broadcasting (DMB), digital video broadcasting-terrestrial (DVB-T) and DVB-handheld (DVB-H), and global positioning system (GPS).

Isaac, Jesus Tellez (2008) discusses an emerging ad hoc network, in which vehicles constitute the mobile nodes in the network. This type of network aims to support communications requirements for V2V and V2I ITS applications.

Long-range communication using cellular data transceivers such as, Global System for Mobile Communications (GSM), General Packet Radio Service (GPRS), third generation Universal Mobile Telecommunications System (UMTS). Moreover, dedicated transceivers e.g., for deployed toll collection systems - dedicated short-range communication (DSRC) can also be used.

Although the following chapters are based on the framework that uses a wired communication approach, the review of wireless communication technologies in this section is done to indicate the replacement of wired with wireless communication technology as an improvement of the framework design.

2.5.1.a *Short range technologies*

Short range communication in ITS can be categorised into two sections; vehicle-to-vehicle and vehicle-to-infrastructure communications. There are different technologies (discussed below) that are used based on the application such as toll collection, parking fee collection, roadside safety inspection, and credentials pre-clearance. Short range communication is used for exchanging information between two cars for example, one car warns the other car of the traffic ahead.

The vehicle-to-infrastructure communication system differs intrinsically from wide area wireless systems such as cellular. The former benefit from being in a confined geographical area (few hundred feet at most), and therefore, are less susceptible to multi-user, multi-base station interference than systems that cover a whole metropolitan area. The key issues centre around the adequacy of the different systems proposed (IR, RF Active, RF Passive) to accommodate the user requirements and their flexibility and expandibility towards the goal of national compatibility.

Dedicated Short Range Communications (DSRC)

Biswas, S. (2006) discusses the DSRC standard that offers wireless communications capabilities for transportation applications within a 1000 m range at typical highway speeds. It provides seven channels at the 5.9 GHz licensed band for ITS applications, with different channels designated for different applications, including one specifically reserved for vehicle-to-vehicle communications. The ITS safety applications that could leverage the new DSRC standard include any system that can be enhanced by allowing information to flow between vehicles and vehicle and roadside infrastructure. Examples of such applications include en-route driver information propagation, collision warning and avoidance systems, and adaptive cruise control systems.

Bluetooth

Bluetooth as the technology that facilitates both voice and data transmission, and operates in the unlicensed industrial, scientific, and medical (ISM) band at 2.4 GHz over a small distance (~10 m) using short range radio links. It has a lower data rate than Wi-Fi (less than 3 Mb/s), and its indoor range is typically 2–10 m. The main advantages in terms of automotive requirements are that Bluetooth requires low power, is low cost, low complexity and is robust Dar, K. (2010).

Selvarajah, K. (2008) and Fengzhong Q. (2010) confirm that Bluetooth is currently the most widely used automotive wireless technology for in-vehicle communication due to its maturity. In fact, there have already been a number of Bluetooth-enabled intra-vehicle applications.

2.5.1.b Long range technologies

Long range technologies are primarily used for V2I ITS applications. Dar, K. (2010) discusses infrastructure- based technologies such as cellular networks (e.g., GPRS, EVDO, and 3G) equipped with several base stations can be used to relay communication signals and cover a long range. They are suitable for some ITS applications but due to time-critical support they have low latency at the expense of reduced reliability. This type of long range communication is not suitable for broadcasting purposes since they support point-to-point communication. Cottingham, D.N. (2007) states different communication technologies including various versions of the IEEE 802.11 standards, the 802.20 Mobile Broadband for Wireless Access standard, and the 802.16e Mobile WiMAX standard have been proposed to enable this new generation of sentient vehicles. With the technical capabilities, it can offer high speed data and portable connectivity. It can be combined with cellular networks as a layover to increase capacity and used for a Vehicle to Infrastructure (V2I) long-range communication.

Wei N. (2011) proposes a novel V2I communication system providing triple play services based on radio-over-fibre technique is proposed, which makes the best of enormous bandwidth the future fibre-to-the-curb access would offer.

Satellite Systems

Satellite communication technology is a well established with several ITS applications using it for their services. At a basic level, satellite communication offers location/ positioning for a vehicle and with this ability, many transportation safety and efficiency applications can offer location-specific applications such as navigation, fleet management, emergency service management, etc.

Tacconi, D. (2010) states satellite communication technology complements wireless sensor network (WSN), which consists of wireless sensor nodes. This system can be used, to significantly improve the efficiency of existing transportation systems.

2.6 ITS and traffic management

Various methods have been used to control the speed of vehicles. These may be traditional sign advisory boards or more recently variable message signs showing advisory speed limits. Heydecker, B.G. (2011) discusses how variable speed limits are used on motorways to manage traffic flow with the intention of improving capacity and hence throughput of traffic. Their consideration is that in order for the control of traffic speeds to affect the quality of traffic flow speed should have a causal influence on the traffic flow. This is distinct from the approach of flow control to modelling of traffic flow in which density is taken to determine speed, and hence flow; there is some accordance with models that use different relationships between speed and density according to circumstance.

Carlson, R.C. (2011) discusses the various traffic control measures that have been proposed to alleviate traffic congestion but are known to face limitations. For example,

- ramp metering may be valuable, but its efficiency is limited by the available storage space at on-ramps;
- variable speed limits (VSLs) are valuable for traffic safety (reduction of accidents), but their current usage has hardly any positive impact for the increase in throughput or decrease in average travel times;
- route guidance is most useful under non recurrent (e.g., incident induced) traffic congestion.

In the next section, the different strategies and algorithm approaches aimed at improving traffic efficiencies are discussed.

2.6.1 Algorithm Development

Hegyi, A. (2008) developed a speed limit control algorithm that resulted in a speed limit control plan, applied as a feed forward control signal to the traffic. They concluded that there are two main approaches for dynamic speed limit control aiming at flow improvement. The first is the homogenization effect that typically uses speed limits above the critical speed (i.e., the speed that corresponds to the maximal flow). These speed limits do not limit the traffic flow, but only slightly reduce the average speed (and slightly increase the density). The second is focused on preventing traffic breakdown or resolving existing jams by reducing the flow by means of speed limits. The goal of the flow reduction is to resolve jams by limiting the inflow to them.

Jin, Wen-Long (2010) analyses the impacts of lane-changing traffic and the corresponding traffic dynamics used the LWR model (Lighthill and Whitham, 1955; Richards, 1956). This model states that traffic dynamics are described by changes in (x, t) -space of three aggregate variables: density ρ, speed υ, and flowrate *q*. The model is written as:

$$\frac{\partial\rho}{\partial t} + \frac{\partial\rho V(\rho)}{\partial x} = 0 \qquad \text{-------- (1)}$$

which is based on three assumptions:

- the fundamental law of traffic flow
- $q = \rho v$ -------- (2)
- traffic conservation

Xiao-Yun Lu (2010) discusses one of the many strategies to manage the traffic on freeways due to the rapid increasing freeway traffic. It has been gradually recognized that ramp metering can directly control the average density immediately downstream of the onramp. They propose a control strategy for combining Variable Speed Limits (VSL) and

Ramp Metering (RM) to maximize the flow of a recurrent bottleneck which can be modelled as a lane reduction.

Carlson, R.C. (2011) discusses how the increase in traffic flow control enabled via variable speed limits have proposed new motorway traffic management tools. These tools are based on sophisticated optimal control methods and may face difficulties in practical field implementations. A straightforward local traffic flow feedback controller that relies only on readily available real-time measurements (no online model usage and no demand predictions are needed) was proposed. It was found that the feedback approach approximates the efficiency of the optimal control approach. This is a much more robust, and easy to implement. It also considers practical and safety requirements that may be necessary its application in the field.

Papageorgiou, M. (2008) reviews various traffic control measures that have been considered and partly implemented in motorway networks to alleviate traffic congestion. These could be classified in four groups: ramp metering (RM), variable speed limits (VSL), route guidance (RG) and emerging vehicle-infrastructure integration (VII) systems. Based on their review of traffic control measures, they propose a novel and efficient motorway traffic management tool, Mainstream Traffic Flow Control (MTFC) and analyse its possible implementation and principal impact on traffic flow efficiency. It is concluded that VSL, suitably operated and enforced, is considered as one (out of several possible) way(s) for MTFC realisation, either as a standalone measure or in combination with ramp metering.

2.7 Influencing factors driving technology to end users

During this research, it was identified that whilst a large amount of focus is given to research and development of ITS, the factors that drive new technologies in the market and have influence over product launch is generally overlooked.

Additional aspects include financial, legal, and organizational issues. For example, what will be the cost of deployment, and how will it be covered? Will the deployment leverage on existing systems and user-portable devices, such as smart phones? What will be the first set of applications deployed? How would authorities and services be instantiated in a heterogeneous environment that would be subject to legislation? Innovation is necessary, of course, in terms of market introduction. Without deep penetration of the solution (in vehicles and/or the infrastructure), benefits for the final user (the driver) will be exceedingly limited. No one would agree to pay for something that will be useful only at some time in the future. Responsibilities, legal implications, and liability issues should be clearly specified.

When a new product or new technology enters the market, there are few challenges it has to face. Several key influencing factors affect the way the product/technology penetrates the market. Due to this, effort and time put behind these processes are quite cumbersome but towards the end become a deciding factor affecting the product launch. Burchill and Fine (1994) give a basic and simplified version of a generic product development process shown in Figure 2-2. This model suggests that product concept development is one of the earliest tasks to be completed in any product development. This generic model can be seen applied to any industry, ranging from pharmaceutical to electronic products.

Figure 2-2: Simplified model of generic product development process

However, when looking at the above model at a lower level the main factors (which arguably can have a number of subsets) evidently influencing product launch are:

- Customer Demand (Customer requirement)
- Competitive pressure
- Product Differentiation
- Technology (Product engineering)
- Market dependencies and
- Business case
- Legal Challenges (Legal / legislative impact)

These 7 influencing factors were validated by Car OEM experts from renowned auto industry.

<u>2.7.1</u> <u>Customer Demand</u>

One of the common driver of new products into the market is the lack of it being less “customer requirement” focussed. Fuchs, C. (2011) states that customer empowerment constitutes a promising positioning strategy that managers can pursue to create a competitive advantage in the marketplace. Kujala, S. (2008) has done a study on user involvement, particularly in product-development contexts. It was investigated how early user involvement could be effective in product development, especially where the large number of users makes their participation impossible.

In the market, the factors affecting customer's decision include his/her preference, product price, quality of after-sales service etc. For example as a first stage (identifying, developing), the customer may buy a car from manufacturer. Once purchased, within the second stage (stabilization), the car needs after-sales services both for repair and maintenance service. This will be required until the car is discarded in the third stage (declining). The customer may buy a new car from the same manufacturer again, and the relationship can translate into the different stages as discussed by Chuan (2007). They further refer to a survey conducted by J.D.Powers and Associates that found the customer has committed hope of high level of after-sales service, because it is the first time for them to realize their dreams to own a car even whilst they lacked the experience of using it.

Convenience is also one of the desires that lead product acceptance into the market. In the automotive industry different developments are ready for implementation. Bluetooth solutions for example is a consumer oriented application. Other examples include applications such as mobile phone, navigation system or different portable devices.

Research initiatives such as Invent, (2009) focussed in evaluating new technologies such as driver assistance systems related to innovation, acceptance, and the consumer demand. New technologies need to be designed to be used safely by all kinds of drivers in all kinds of traffic situations. Invent found that in order to achieve market acceptance, they must have a user-friendly design adapted to consumer needs.

With regards to ISA acceptance, research studies have indicated that drivers are more in favour of advisory and warning systems and that as systems become stricter in preventing speeding, they become less preferred. In Tilburg, Sweden public opinion surveys and field trials suggested that society has begun to recognise the harm caused by speeding. However, some drivers remain resistant to the concept and an overwhelming 62% of Tilburg drivers still evaluated driving with ISA less positively than driving without ISA (Jamson, S. 2006).

Piao (2005), finds in a separate survey conducted by a European project Stardust, that among the three different types of ISA surveyed. ISA, which gave a warning, was the most favoured (64% to 76%); Mandatory ISA was the least popular system with only 9% to 13% acceptance level, whilst 3% to 6% of the drivers rejected all different types of ISAs.

2.7.2 Competitive pressure

In order to maintain a competitive edge, many companies launch new products to differentiate their products and technologies from others. Beaume, R. (2009) discusses that during the 1980s, the increase in competitive pressure put emphasis on the ability of industrial firms to improve quality level, reduce cost and time-to market of new products and to manage the increasing complexity of products. Many industries addressed this shift: automotive, medical devices, consumer goods, and electronics. This competition determines the time and evolving of new products.

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Vives, X. (2008) provides general and robust results on the effect of indicators of competitive pressure on innovation. They further clarify the robust relationships between different measures of competitive pressure and R& D.

Gallagher, S. (2012) discusses a fine example of the recent blue-ray and HD-DVD technologies. Both technologies aim to offer exceptionally similar end product i.e. high quality video and audio. However, in order to maintain the competitive edge one group differentiated the technology and approach of it into the market. This led to one being accepted and the other rejected.

Holweg, (2001) performed a study that concluded that the rate of innovation in the automotive market has increased significantly. This meant that the car manufacturers have to face the challenge of responding to customer demand and competitors action. Whilst being constrained at the same time by much shorter sales windows and lower overall volumes per model to cover their costs.

Chuan (2007) found that in developing a new product, *competitive pressure* has to be taken into consideration. Data from China Automotive Information Conference shows that the profit ratio of automotive manufacturer dropped 50% in 2004. The fact is that the competition between manufacturers becomes tough, and this results in excess of supply.

Increasingly automotive manufacturers are aiming for mass customisation, providing such a variety of products that nearly everyone can find what they want. More product variety is causing escalating costs and complexity in manufacturing. Manufacturers responded to fierce competition with shorter product life cycles and quicker delivery of new products to the market. Heinecke, H. (2005) reports that there is a need to innovate, continuously develop and provide distinctive novel features in a highly competitive environment. This is particularly noteworthy in the premium car segment.

Holweg, M. (2001) states that product variety is a key factor in determining future distribution strategies of vehicle manufacturers, and this is inextricably linked with a company's model lineups policy dictated by the life cycle and model range requirements of the marketplace. Discussing product proliferation is a complex issue in the car industry, as there are many factors influencing the overall variety of products offered to customers. First of all, there is the number of models offered by each vehicle manufacturer. Each model in turn is offered in a certain range of specifications and combinations of options, which defines the individual product variety. The third and least obvious factor of product proliferation is the product life cycle, as choice offered to the customer not only depends upon the variety offered, but also upon how often that choice is renewed. For example, shown in Table 2-2 below is a product variety example, UK 2009.

OEM	Model	UK Sales 2009
Ford	Fiesta	22,635
	Focus	13,622
Vauxhall	Corsa	16,379
	Astra	13,190
Volkswagen	Golf	11,787
Peugeot	207	9,161
Mini		8,634
BMW	3 series	7,465
	1 series	6,671
Toyota	Yaris	6,896
Source: telegraph.co.uk (By Graham Ruddick Published: 11:18AM BST 06 Oct 2009)		

Table 2-2: Current product variety examples, UK 2009

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In the automotive industry, the character of customer lifecycle is different from other service industries such as telecom. In the automotive industry, the customer creates profit for the automotive manufacturer as soon as they purchase a car and then the after-sales service period will last long, but the profit is low per-transaction. This continues even when the customer replaces their old car in the future as this continues to bring high profit to the automotive manufacturer. So the customer relationship may jump among the different phases in lifecycle, and the value curve likes heart beat in the long run (see Figure 2-3).

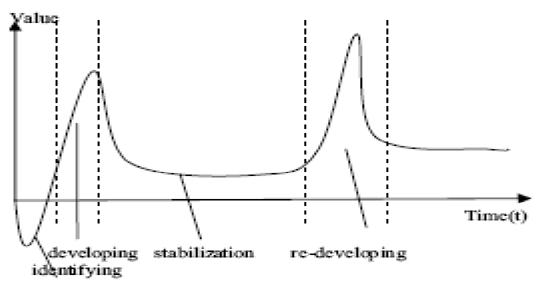


Figure 2-3: Customer Value Curve in Customer lifecycle

2.7.3 Product Differentiation

Beaume, R. (2009) discusses that for the last 20 years, OEMs and suppliers have dramatically increased the pace of new products launches with increased innovative features. As a direct consequence, automotive companies face an emerging challenge to increase the frequency, reliability, radical nature and profitability of the innovations developed in research and advanced engineering, and at the same time to maintain their ability to develop more vehicles than ever in a context of highly tight constraints on quality, cost and lead time.

Pasek, Z.J. (2010) discusses how automotive OEMs have long recognized that for production efficiency, satisfactory product variation flexibility, and control of new product development costs they have to base their designs on modular product architectures. Manufacturers are striving to optimize the number of variants derived from a limited number of basic platforms. The balancing act requires them to decide whether a limited platform strategy can deliver product differentiation while retaining the benefits of economies of scale.

Favourable perceptions of product quality and value by customers lead to differentiation and higher brand loyalty, which, in turn, lead to higher buyer switching costs that can be exploited to enhance current profitability and cash flows.

2.7.4 Technology

The design of a product has a significant influence in its acceptance by the end user. Conceptually a product could be hugely productive and appealing but due to poor design engineering may not make it into the market. At the same time, the development process also influences the product launch and this applies to all industries.

VanDriel, C. (2005) concluds from their research that standalone ADAS are not satisfactory. Consequently, integrated ADAS are needed that make use of each other’s information to extend their individual fields of activity. Consider, for example, warnings for imminent crash situations based on sensor data fusion or warnings for downstream traffic conditions based on intervehicle communication.

Newer technologies for example Bluetooth in short range communication is significantly influenced by their design. This technology has become an accepted standard for wireless connectivity in the fields of mobile telephone systems, office communication, multi media devices, and consumer electronics. Additionally, there is a market for technical tasks like real time control, data acquisition, and monitoring where there is a need for wireless connectivity, too.

Shrinath A. (2004) has found the enormous rise of advanced technologies being implemented in automobiles. Simple functions, which were considered, to be highly complex in the past and difficult to implement, are being put on the vehicle not only on their own but are modified with more functionalities. They go further to state that systems from engine control to multimedia and infotainment services are implemented in today's automobiles due to the advances made within the electronics and communications fields. This has led to the emergence of concept of providing the customer with all possible solutions and has increased demand for a regulated mechanism for data transfer for the devices embedded in a car. In order for this to be implemented for safety critical systems of a car, this would take some time, due to adverse effect and failures that such systems could lead to. However, such networks are already used in cars, such as multimedia, doors, seat adjustments, and trunk release.

Therefore from the above discussions we can see how *product engineering* whether in favour of the technology or in some cases as a limitation of it has an influence in its acceptance by the end consumer.

2.7.5 Market dependency

Market dependency is another key factor that influences a new product which is being launched in the market. Regional products may attract the local customer, but when marketed outside the region / country they may become a total failure. Market dependency is not only influenced by customer acceptance but to a certain extent driven by the local legal system. A product, which may be legally approved in one country, may not be allowed to be used in another.

Levy, L. (2008) indicated the importance of market dependencies in their research. They state “Automobile companies exhibit considerable variation in their strategic responses to climate change. U.S. companies had an early response to the issue. They aggressively challenged the need for emission controls, and have invested in a range of long-term technological approaches to emission reductions without committing to production vehicles. European companies, by contrast, have been less engaged in public debates about climate science, have accommodated regulatory demands for significant emission reductions, and have invested in more incremental, short-term improvements to conventional internal combustion engine technology. The different economic and market environments in each region offer only a partial explanation for these divergent strategic responses”.

For example, in the US all passenger cars must be equipped with an occupant classification system (OCS) as defined in the National Highway Traffic Safety Administration D.O.T. document. This, however is not the case for the rest of the world passenger car market.

Levy, L. (2008) states that the impact of low-emission technologies on price was seen as a problem even in Europe. In their paper, they have stated an example where a Ford Europe manager noted that customers will not pay a premium for fuel economy. It is a midlevel concern for consumers in Europe, which if compared to the United States is considered as a high concern. Companies related a number of experiences in which consumers reacted negatively to cars that pushed the environmental envelope, and these experiences appear to have become institutionalized as conventional wisdom. In Europe, Daimler, Opel, and Volkswagen all had introduced lightweight, fuel-efficient vehicles that had met limited demand. The barrier to new technology was not just price. European managers demonstrated a greater awareness that the success of new technologies was contingent on broader social and institutional change. These different perspectives on consumer preferences explain, in part, the differences in innovation strategies. U.S.-based companies were planning a car of the future that would not require any change in transportation patterns, road infrastructure, or consumer behaviour; rather, the burden of emissions reduction would be placed on advanced automotive technologies. This led to a focus on longer term and more radical approaches to emission reduction, without sacrificing conventional car features. Such efforts were necessarily expensive, generating pessimism about the likely markets for such cars. European efforts, on the other hand, comprised more balanced, incremental investments in short- to medium-term emission reductions. Consumers were expected to play their part in adapting to new types of vehicles and to the changing role of private cars in the transportation system.

2.7.6 Business case

A *business case* analysis prior to product launch has a vital influence and is not limited by the product industry. For example, within the pharmaceutical industry business case is one of the most significant factors influencing a product launch. Kleczyk (2008) states "assuming a fixed research and development budget, the management issue includes deciding on which new products to develop, continue to research, terminate, and invest in". In making these decisions, managers face tradeoffs between risks, returns, and time horizons for future payoffs. In theory, such tradeoffs are easily tackled by optimization problems; however, the complexity and uncertainty of the new drug development process make the solution hard to obtain and force the management to employ less complicated and therefore less precise methods of new product identification".

There are research initiatives like Invent, which aim to contribute by looking into economic assessment with potential benefits and costs related to new technologies. Invent (2009) research looks deeply in to profitability calculations for users and system manufacturers (e.g., break-even analysis) and macroeconomic cost-benefit analysis comprising savings in time, vehicle running costs, accident consequences, and emissions. It also analyses social impacts including income, employment, and working conditions, as well as financial and socio-demographic accessibility.

Jamson, (2006) discusses that the British research in 1997 on ISA systems which was funded by the UK Department of Transport had an exceptionally wide remit. It covered virtually every aspect of ISA, ranging from a review of suitable technologies, through studies of public attitudes and willingness to pay, to simulation modelling to examine side effects in terms of travel time and fuel consumption and finally to predictions of collision savings and systems costs and benefits. This kind of study helps the industry create a compelling business case for new technology.

2.7.7 Legal Challenges

Blau, (2000) states that other factors affecting highly regulated industries and other consumer industries where safety is critical include *legal challenges* and *competitive pressure*. In formative industries such as biotechnology, regulatory requirements continue to tighten, as public perception is often more influential than science in the approval process. Engineers are comfortable building process models. However, they infrequently think about the development of new products or the selection of new products as processes.

Research to find the impact of new automotive technologies and the influence they have on traffic provide an assessment of comfort and safety improvement. Projects like Invent (2009) are well supported and used by the government as they also investigate legal conditions, regarding product liability, type approval and liability issues of the systems. There are questions such as:

- What product liability / negligence risks are created by new assistance systems?
- Are new legal regulations required for the introduction of these systems?
- Must the driver be able to override system interventions at any time?
- What are liability implications?
- What legal problems can be expected if not all vehicles are equipped with the system, e.g., in the introductory phase?

Invent, (2009) discusses these criteria that help to identify areas in which feasible technical developments are subject to legal conditions.

Van Driel, C. (2005) discusses that over the coming years, drivers will have an increasing variety of Intelligent Transport Systems (ITS) at their disposal, including ADAS. ADAS are in-vehicle systems that support the driver with the driving task. High expectations rest on ADAS (European Commission, 2002; Ministry of Transport, 2004). Governments expect them to lead to a more efficient, safer and cleaner transport system.

Van Wees, K. (2005) states that a variety of ADAS has been and is still being developed, aiming to make car driving more comfortable and safe, while at the same time enhancing traffic efficiency. However, the successful implementation of ADAS is affected by a variety of technical and nontechnical issues, one of them being possible implications in the field of legal liability.

Jamson, S. (2006) has found that, with rapid developments in technology, ISA has become more financially viable; the barriers to implementation are more concerning public acceptance and political will. Carsten, (2005) states how Sweden is taking a number of steps to promote ISA by equipping the Swedish National Road Administration vehicles with ISA systems.

Piao, (2005) discuses how policies and regulations could have significant impacts on acceptance of ISA systems. In situations of strictly enforced speed limits, there could be an increase of 10% to 20% in the number of drivers who took ISA either attractive or extremely attractive according to results from UK and Norway.

2.8 Justification of Research

Hegde (2008) discusses how a modern automotive system has become a complex electromechanical system, whose comfort, safety and performance requirements have warranted their implementation by way of multiple number of ECUs in it. The number of Electronic Control Units (ECUs) and the amount of functionality are increasing with every new car coming on the road. As a result, automotive OEMs are facing difficulties in integrating subsystems, which are designed and implemented by multiple Tier-1 vendors.

Wang, F. (2010) states that, we have experienced a few “road bumps” over the last few years in ITS research and applications, especially in relation to system-level traffic control and management. Traffic management, road safety, efficient travel and similar transportation subjects can be improved, particularly at the system level by employing new thinking and a multidisciplinary approach. This can be achieved with new methods of conducting intelligent control, management at the system level using an ***integrated*** approach.

Jesty, P.H. (2011) states that the need for ITS architecture was recognised in the early 1990’s, when the number of possible applications and services that ITS could provide increased tremendously. However, it was recognized that instead of producing unique architectures for each deployment, it would be much more efficient to have framework architecture, from which individual ITS architectures can be developed. The use of such framework architecture would save money by enabling issues to be identified and resolved in the early stages of the system lifecycle.

Böhm, M. (2008) states that the most critical technical aspect for the development of wireless communication between infrastructure and vehicles is the *secure* and *safe* transmission of the safety-relevant road information in real time in all kinds of traffic situations to all vehicles within a specific road segment. Kosch, T. (2009) highlights the issue of *standardisation* stating that that wireless communications for intelligent transportation systems promise to be a key technology for avoiding the traffic nightmares of today's accidents and traffic jams. But there is one significant challenge to be overcome before such a cooperative system can be put into place: standardisation. Soon the automotive industry will have numerous different systems urging to penetrate the market to offer their services to the end customer but due to systems integration they all will face a tremendous challenge.

Another issue, which will soon come into view is computing power. Wang, Z. (2009) states for example WIM has its own limitations. When the vehicle passes over a weight platform with a certain speed, there are some affecting factors like, the time of the tire on the platform is short. The force on the platform is not the true axle load because there are factors, such as speed, vehicle self-resonant, road incentives, tire driven, that affect the performance of WIM thus preventing it from achieving higher precision results. This indicates that there are some technical limitations at vehicle end. However, this can be resolved using complex algorithms that take such factors into consideration before calculating the weight of the vehicle, but this implies *overloading the vehicle with computing power* such that the vehicle itself will need to become a computer, technically capable to perform these functions and in turn restricting its own primarily ability for serving transportation.

Various ITS systems (ISA, WIM, etc.), have their own advantages and applications, aiming to create a safer and efficient traffic transportation environment. On the other hand, these systems being proposed have their own design and protocols and ways they communicate within themselves in the vehicle or with the infrastructure.

Chapter 2: Literature Review

Papadimitratos, P. (2009) states recent concerted efforts in academia and industry point to a paradigm shift in intelligent transportation systems. Vehicles will carry computing and communication platforms and will have enhanced sensing capabilities. They will enable new, versatile systems that enhance transportation safety and efficiency and will provide infotainment and with them there is the critical issue of technical capabilities, integration, compatibility and standardisation.

Every element (vehicle applications, vehicle to vehicle communication and infrastructure tools) within ITS adhere or try to maintain an integrated model by using some form of standard protocols, but each element achieves this within its own limits. The gap exists with a lack of standardisation, complete integration and managing ITS applications at the infrastructure end.

In order to address the research gap discussed above, the aim of this research is to develop a framework for the communication of various ITS and in-vehicle systems within themselves and with the infrastructure. This aim will be realized by achieving the objectives highlighted in Section 2.9.

From the various reviews conducted, it is found that one of the most efficient ways of traffic control can be achieved using variable speed limit. Xiao-Yun L. (2010) discusses how traffic control methods such as ramp metering may fail when used as a single traffic control method if the demand from that on ramp is too high to avoid traffic spilling back onto arterials. However, by the use of additional control strategies such as variable speed limit (VSL) results may improve not only in traffic control but also in safety. Several implementations have been conducted in the UK, France, Germany and Netherlands using VSL to harmonise the traffic mainly for safety.

Use of traffic control strategies such as variable speed limit notifications rely heavily on the driver of the vehicle, and since drivers do not adhere to such advisory (and non obligatory) messages always, proposed models and solutions fail. Dynamic speed control using ISA is one way of controlling the speed of a vehicle using ITS technologies that can address this issue.

Projects like DRIVE, CVIS & COOPERS aim to look at vehicle-to-infrastructure communication and work initiated by such projects is only the first step towards improved communications and better integration in road transport. These initiatives typically look at technologies that offer unidirectional and not bidirectional solutions. For example, the Radio Data System / Traffic Message Channel, direct debiting of tolls, road pricing charges and parking fees, are technologies covered by the DRIVE initiative. These types of technologies send information from the infrastructure to the vehicle or vice-versa. Although these can be considered as a vehicle-to-infrastructure solution, the methodology and concept proposed in this research uses a bi-directional approach with an integrated framework. The proposed solution aims to send and receive data between both the vehicle and the infrastructure. This makes the vehicle, ITS systems and infrastructure a single environment. A multi system support is used to validate the proposed architecture. Moreover, both ITS systems operating with the infrastructure as one, is illustrated as a differentiator and enhancement to past V2I projects.

Details of this proposed solution which is one of the objectives for this research are discussed in the next chapters.

2.9 Research aim and objectives

The aim of this research is to design and develop a framework for integrating in-vehicle enforcement ITS systems as a part the infrastructure. This will be realised by achieving the following objectives:

- To investigate novel integration methodologies for in-vehicle safety and enforcement systems,
- To design a conceptual framework through the analysis of the functional characteristics of different ITS systems and communication technologies,
- To model and realise an integrated vehicle-infrastructure safety and enforcement solution based on the conceptual framework and the use of simulation tools,
- To demonstrate the potential of the developed framework using a micro-simulation tool for the evaluation of traffic performance of a motorway,
- To evaluate the outcomes of the prototype systems in order to propose a toolkit that enables the time-to-market estimation of new automotive technologies.

2.10 Methodology

This research has identified various gaps within ITS enforcement systems related to systems integration and communication. To address these issues a novel framework that allows ITS systems to be integrated and more importantly communicate not only with each other but also with the infrastructure was designed. This framework was then tested with 2

ITS systems (dWIM and ISA) that were adapted for this work. Part of the work included development of an algorithm that put the ISA system to test as a part of the framework. The traffic improvement algorithm (TIA) was tested using simulation tool. The dWIM system was tested on the bench and evaluated with bench validate results, due to limited resources,

Another gap that was addressed as a part of this research was a time to market estimation of a new technology (automotive). To address this gap a toolkit was developed and tested with the 2 existing systems.

2.11 Summary

There are various ITS systems some are developed and some are under development; their introduction had started over 3 decades ago. These systems have been widely used as standalone, but there still exists a need for them to function together on a vehicle and interact with the infrastructure.

From the various reviews in section 2.5.1.a it was found that a beacon based ISA has been extensively researched from all aspects including user acceptance and technology. This beacon based ISA technology concept formed an appropriate system option for one the ITS nodes within the proposed framework.

ISA as a VSCS has benefits such as reduced driver workload and reduction in accident rates. In addition, it is being accepted by a number of government agencies, vehicle manufacturers and ITS suppliers. This system also has drawbacks like high implementation costs, limited public acceptance and systems dependence that may encourage drivers to drive up to the limit instead of using moderate speed, based on road conditions. Such drawbacks prevent the system to penetrate the market easily.

There are also issues like:

- Product liability - manufacturers hold responsibility if the system fails to perform correctly.
- Driver liability – since drivers do not posses full freedom of action, they cannot be expected to bear the entire liability for possible consequences like accidents caused due to system failure.
- Public authority liability – the public authority as the operator of the infrastructure and transmitters of the signal is also a participant and must bear appropriate responsibility for any occurrence since the driver may have been able to avoid any accident by driving faster at the appropriate moment.

The literature review into existing WIM systems indicates that there is a strong requirement for an improved in-vehicle or on-road WIM system that is cost effective and accurate. Bernard, J. (2010) discusses the technology requirements of an in-vehicle weigh-in-motion system.

The development of an efficient sensor dWIM system is beyond the scope and was not an objective of this research. However, dWIM is another sound system option that was considered as an enforcement ITS node. Hence, a much scaled down version of a dWIM was developed to prove the concept and achieve the research objective.

In section 2.5, a contentious area is entered, that is, determining which communication systems are best suited for the proposed enforcement systems. It primarily contains a broad analysis, review, and assessment of the various communication technologies that are applicable to the research.

This chapter presented a description of the work that exists for integrated frameworks for automotive components. It also identified the research gap as the lack of a framework that allows integration of different automotive technologies and the influencing factors driving the technology into the market. This has inspired the work in this research and the results are presented in the following chapters.

This research and the technology reviews indicate that there are various approaches for integrated framework within the transport industry. However, there are few practical projects or implementations that would assist the transport industry to compare the advantages and benefits of ITS architectures.

This project also provides value added benefits in one of the key areas of transportation that is traffic enforcement. ITS may provide safety benefits, and when these are implemented by enforcement agencies using technologies described it will help prevent a hazard rather than minimise the effects.

In section 2.6, a review of different traffic management strategies has been discussed. It is clear that flow control and density can be managed by controlling vehicle speed in traffic. Therefore, this research aims to develop a novel algorithm taking such traffic parameters into account and giving out an optimum road section speed limit that enables efficient traffic control. This algorithm is implemented using ISA technology that controls the speed of the vehicles, thereby making flow control more efficient than an advisory speed control system such as VMS.

Chapter 3 : Integrated Framework

3.1 Introduction

From the literature review chapter, the gaps in the area of ITS have been identified. The main issue with ITS systems in research and practice is the lack of an integrated methodology that allows ITS systems to be integrated with infrastructure. Although in vehicles ITS systems can function independently or with each other, integration of this system with the infrastructure still remains unexplored for more sophisticated ITS systems with complex applications such as enforcement and traffic management. Such controlled ITS systems communicate with the infrastructure but as separate elements rather than as one. This makes information sharing difficult and the technology complicated. Therefore, the benefits of the vehicle and infrastructure operating as one integrated system are lost.

This chapter proposes a novel framework that would allow ITS within vehicles to communicate and function with the infrastructure. The integration methodology and different components of the proposed framework are also discussed in this chapter. The framework proposes a technique that can be used by the automotive industry (or a similar requirement industry) to gather the vehicle's information and communicate with the infrastructure. It can assist in vehicle diagnostics, monitoring or even control of the various parameters of the vehicle (for example enforcement applications).

3.2 Integrated Framework Architecture

In this section, the proposed framework is presented at 2 levels. The first level is the high level showing the various components in a generic format. In the next level, the generic components are replaced by real-time ITS modules and functionality of each module is discussed. The evaluation and validation of the framework are discussed the following chapters.

3.3 Conceptual Framework

The vehicle-infrastructure framework is split into three components: vehicle, vehicle-to-base communication and base network infrastructure. The processes followed by a user in order to apply this framework for integrating ITS systems is also described. These steps illustrate the technique for various enforcement (or even non-enforcement) systems to communicate and form a harmonised ITS environment. The model in Figure 3-1 outlines elements in a vehicle – infrastructure architecture. Users can add various components to this model, and a resultant singular system framework can be developed. The details of each element of the framework are discussed in the following sections.

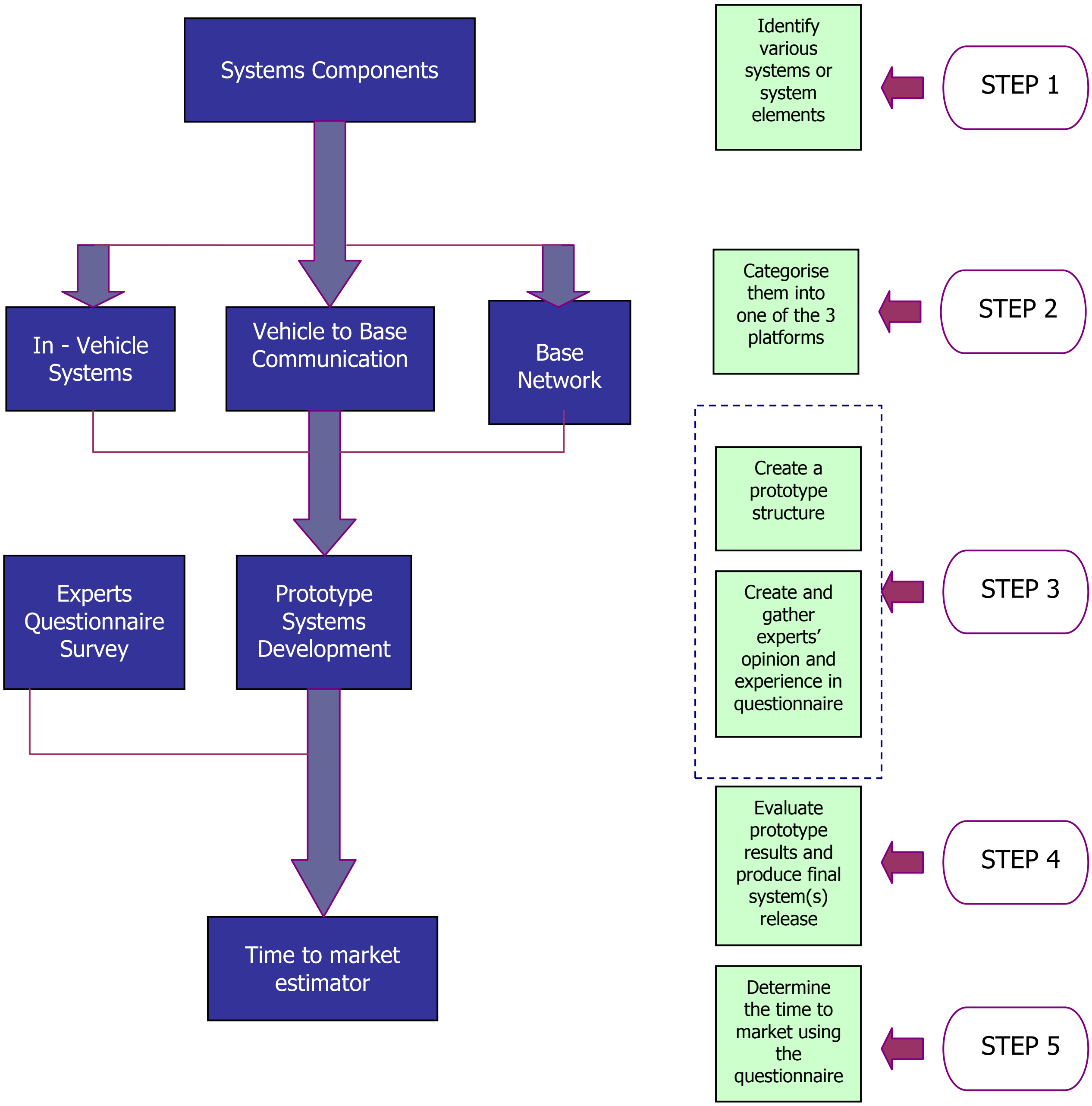


Figure 3-1: Integrated Framework

3.3.1 In-Vehicle Systems

One of the main objectives of the framework is to tackle the interoperability issue, which most ITS designs are ignored. Every system has data inputs and outputs that are shared, or exchanged with other systems. If the data exchange is based on a standard the information sharing becomes easy to realise. This necessity demands a practical framework, which can be applied for the integration of ITS systems within the vehicle, or external to it.

The proposed protocol for an integrated ITS architecture is the CAN protocol. CAN is more widely accepted and has undergone various standard updates due to its popularity in the automotive industry. This has also led another standard J1939 to be built upon the CAN extending its capability to HGVs.

This framework uses these standards (CAN & J1939) at the network and application level to integrate in-vehicle ITS systems with the infrastructure. Typical ITS systems like the anti-brake locking (ABS), collision warning system (CWS), stop and go system all are related to speed limiting and controlling applications. These systems when installed in a vehicle need to interact with each other and the external infrastructure (when necessary). For example, the CWS may need to send the braking signal to the ABS when it detects an unavoidable collision. If these systems are exchanging information on the CAN or J1939 platforms messages can be shared and transmitted to the infrastructure.

3.3.2 Vehicle-to-base network communication

This interface should be capable of supporting various standards, allowing ITS systems to communicate and exchange messages that are made available on the vehicle's network.

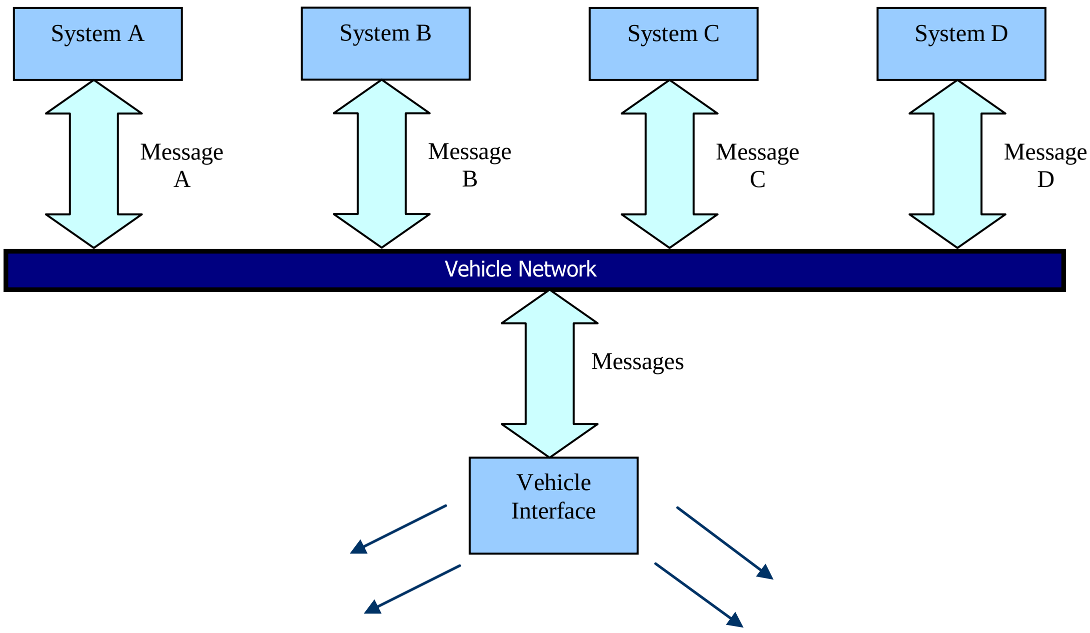


Figure 3-2: In-vehicle systems integration

This above concept is illustrated in the diagram shown in Figure 3-2 that shows how messages are sent from different systems (nodes) onto one vehicle network. These messages are picked up by the in-vehicle interface that communicates with the base network and external applications that are monitoring vehicles.

This structured approach will help in defining the various building blocks of the integrated enforcement ITS architecture. It allows adaptation for meeting the precise needs of different ITS services. This kind of network model supports the ITS architecture requirements, where specific importance is given to identification of key interoperability interfaces and standards. There are various applications for this, a few of them are:

- intelligent speed adaptation,
- dynamic weigh-in-motion,
- remote vehicle diagnostics,
- fleet management, etc,

The vehicle interface forms a key component of the integrated architecture. It acts as a junction where all messages are made available for further processing. The interface can act as a repeater and transmits the messages using short and long-range communication technologies.

Typical short range communication technologies include Bluetooth, dedicated short range communication, Wi-Fi networks. Long-range technologies include GSM, Lower Earth Orbital Satellite systems, Wi-Fi max network. These technologies can be integrated with the vehicle interface to send and receive messages.

Once these messages are transmitted from the vehicle they are then available for the external systems to process and utilise them.

3.3.3 Base network

Depending on the type of application, at the infrastructure applications can reside on small handheld computers or large servers. The main objective of the infrastructure would be to process the messages it receives from the vehicles, and interpret information for users and initiate appropriate processes.

A mobile enforcement computer could be used at the base network to monitor and record the speed of vehicles in a perimeter. The speed of the vehicle is encoded as a message on the vehicle's network. This message is transmitted by the hardware interface that is connected to the communication module. Once the network receives the message it can then interpret the message for the user.

Infrastructure APIs are programmed to communicate with the vehicles' network (through the hardware interface), gather messages and convert them into a format that could be used by end-user applications.

3.4 Application Framework

3.4.1 Systems component analysis

For a better understanding of how the conceptual framework can be applied for real-time ITS applications and also to validate the architecture, this section replaces the conceptual components with real-time components. A visual illustration of this is shown in Figure 3-3.

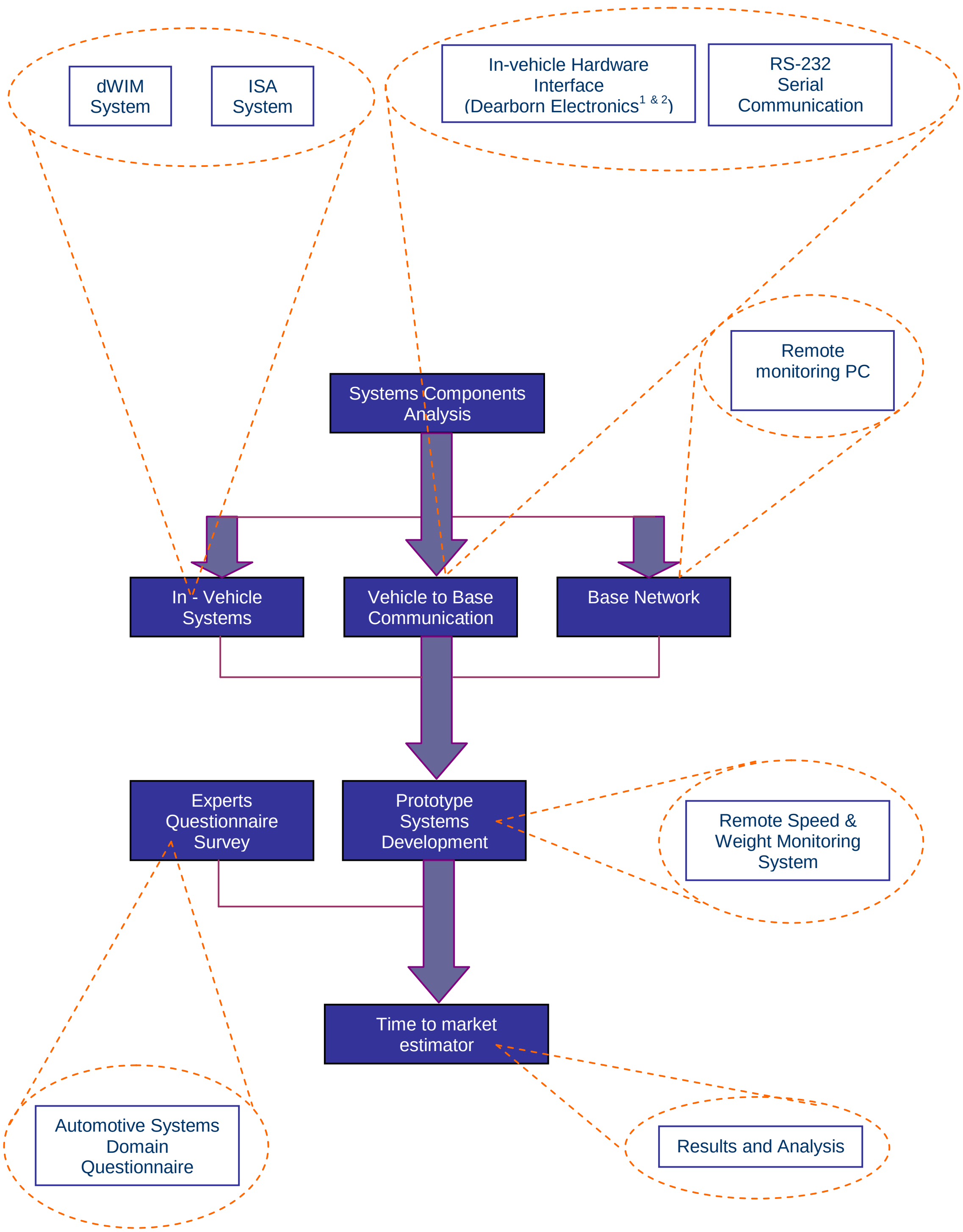


Figure 3-3: Applied ITS Integrated Architecture

1. Dearborn Electronics, (2001), Gryphon Installation Manual, Version 1.1, Dearborn Group Incorporated.
2. Dearborn Electronics, (2002), UNAT Installation Manual, Dearborn Group Incorporated.

In Table 3-1 the different steps taken to validate the framework are summarised, highlighting the various components and level of testing.

Framework components	Simulation	Laboratory	Real-time
In-Vehicle Systems	CANoe Tool		
		Strain Gauge / Loadcell on the bench	
		ISA transmitter / receiver in the truck and PC	
			Strain Gauge / Loadcell on the bench
			ISA transmitter / receiver & vehicle equipped with speed limiter
Vehicle to Base Communication	CANoe Tool		
		PC parallel port and RS – 232 port	
			PC RS – 232 port
Base network	Developed Software		
		Developed dWIM & ISA software APIs	
			Developed dWIM & ISA software APIs

Table 3-1: Framework development steps

This integrated architecture is evaluated using prototype ITS systems such as dWIM and ISA. The details of the various hardware and software components used within this architecture are illustrated in Table 3-2. This table identifies the off-the-shelf systems and the ones that were developed specifically for this project in order to realise the proposed architecture.

Framework elements	System components	Developer	Reference section
dWIM system	**Hardware components**		
	Strain gauge weight sensor	Off the shelf	3.4.2.a
	Strain Gauge Bench setup	N Rangwala	
	Weigh pad sensor (loadcell)	Intercomp	
	Wheatstone bridge	N Rangwala	
	CAN card	Dearborn Electronics	
	Software components		
	dWIM firmware	N Rangwala	Appendix F (F-14 – F-43)
ISA system	**Hardware components**		
	Roadside transmitter	RF Solutions	3.4.2.b
	In-vehicle receiver	RF Solutions	
	Data encoder	Holtek	
	Data decoder	Holtek	
	In-vehicle speed limiter	VDO-Kienzle, UK	
	Software components		
	ISA firmware	N Rangwala	Appendix F (F-14 – F-43)
In-vehicle hardware interface	**Hardware components**		
	Gryphon Hardware interface	Dearborn Electronics	3.4.3.a
	UNAT Hardware interface	Dearborn Electronics	3.4.3.b
Base network	**Software components**		
	ISA Algorithm	N Rangwala	3.4.4.a and Appendix F (F-14 – F-43)
	ISA Software API	N Rangwala	
	dWIM Algorithm	N Rangwala	
	dWIM Software API	N Rangwala	
Time to market Toolkit	Questionnaire & analysis	N Rangwala	6.2, 6.3 & Appendix E

Table 3-2: Standard vs. Developed elements of the framework

Chapter 3: Integrated Framework

Although this prototype architecture uses of 3rd party hardware components, simulation tools and application-specific systems, the design of the framework is such that any device or system can be integrated by adopting this methodology.

There are various types of existing intelligent transport systems, and a number of new ones are being researched to provide efficient performance and applications for the industry. One such application is the traffic enforcement that underlines ITS. Individual drivers and companies gain benefits through driving faster and carrying heavier loads, but society pays the cost in an increased number, severity of accidents and increased road maintenance. Traffic enforcement application is a cost associated ITS application that enables speed limitation and weight restriction to reduce and avoid such issues.

The other component in the prototype architecture is the vehicle-to-base communication interface. For this research wired serial communication was used. However, this mode of communication can be replaced by any other form of communication such as Bluetooth, satellite or other communication technologies discussed in Chapter 2. The in-vehicle interface is installed and integrated within the vehicle and hence becomes a part of the vehicle. However, due to its application and role within the proposed architecture, it acts as a communication component between the vehicles and infrastructure.

The third component of the framework is the base network. This is in the form of a software application that exchanges data between the in-vehicle systems and remote monitoring PC.

The description of the hardware for the implementation of the dynamic weigh-in-motion and intelligent speed adaptation prototypes and the supporting software is detailed in the following sections.

3.4.2 In-vehicle systems

Using the conceptual framework as discussed in section 3.3, the following paragraphs describe the 2 ITS systems (dWIM and ISA) that were integrated as in-vehicle systems within the prototype architecture. It is to be noted that this prototype architecture can support a number of similar ITS systems. However, for the scope of this research and evaluation of the framework only two systems have been used.

3.4.2.a Dynamic in-vehicle weigh-in-motion (dWIM)

It is to be noted that the dWIM system developed for this research was solely for generating weight messages replicated close to those of a real-time dWIM system. The design or the system itself was not intended to be a functional device that could be installed on a vehicle.

A typical dWIM system consists of a number of sensors installed on the vehicle's axle(s). These sensors are connected to the dWIM system's ECU that monitors the strain on each axle, and compares and combines the values to calculate the overall weight of the vehicle. The use of this system allows the monitoring of the vehicle's weight at any time, even when it is in motion without having the vehicle pass on a weigh bridge or use other weight measuring techniques. As a part of the dWIM algorithm and system design other weight factors such as wheel, underbody weights, etc., can be accounted for as a part of the calibration process.

For the purpose of this research, the dWIM system design was done in 2 phases. In phase 1, a bench level dWIM system was developed using an off-the-shelf strain gauge setup. The test platform has a strain gauge fitted at the cross section of the aluminium plate that simulates an axle of the vehicle. This plate in fixed on a wooden base such that loads can be placed easily on it. The output is in the form of resistance, and is too small to be measured directly. Therefore in order to improve the output quality, a low noise /drift amplifier was used. The amplifier was configured for resistive bridge measurement and in particular for strain gauges. Foil strain gauges when attached to a specimen, produce extremely small changes in resistance and require a Wheatstone bridge for full functionality.

Dearborn Electronics, UK has provided a single channel compact CAN card that comprised of a 64 Kbytes memory chip and a UART chip for communication and this was connected to the output of the bridge. This consisted of digital and analogue expansion connectors that allow digital or analogue I/O. This setup is illustrated in the Figure 3-4.

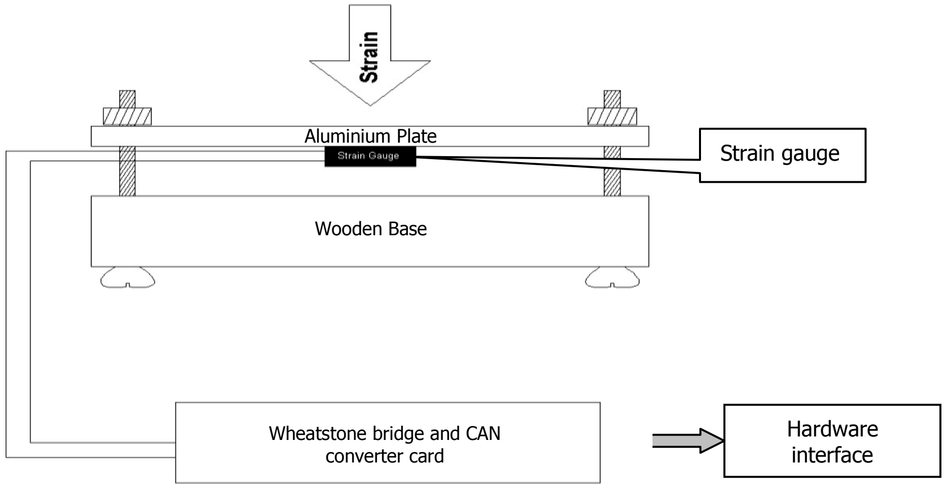


Figure 3-4: Hardware interface 1 setup

Upon placing a load on the platform, the strain gauge gives a corresponding change in resistance. This in turn, gives a change in voltage which is fed to the CAN card. The CAN Card converts this voltage into a CAN message which is sent to the hardware interface that puts it on the CAN bus. The bus is monitored for weight data by the dWIM software Application Programming Interface (API) on the PC (base network; its details and results are discussed later in the following chapter).

As a next step, in phase 2 the setup discussed above was tested again using an industrial weigh pad sensor (loadcell) system (Intercomp) to obtain a comparable weight data to a real-time system.

The analogue data is fed into the hardware interface that converts it to CAN messages. The conversion is done by the firmware which converts the analogue and digital signals into CAN messages that are transmitted through the RS-232 / Ethernet channel of the hardware interface(s) and to the data-monitoring computer. Both RS-232 and Ethernet are common computer communication protocols. The firmware and software API are written in ‘C’, and both were developed specifically for this project.

3.4.2.b *Intelligent Speed Adaptation*

Similar to the weigh in motion, speed control can be categorised as an enforcement application. Vehicle speed adaptation systems aim to change traffic speed distribution and minimize accidents caused by excessive speeding. Intelligent speed adaptation systems not only reduce the accident rates but also aid to the traffic management and flow.

For the implementation of an intelligent remote speed control system, an in-vehicle speed limiting device is interfaced with an onboard computer. This interacts with an infrastructure-based sensor that allows a range of speeds to be adapted by the vehicle for varying applications, such as:

- Management of traffic flow;
- Speed enforcement by the police;
- Excessive speed minimization, and
- Environmental or accident related speed adaptation

In order to demonstrate an intelligent speed adaptation system a beacon based setup was used as a part of the integrated prototype architecture.

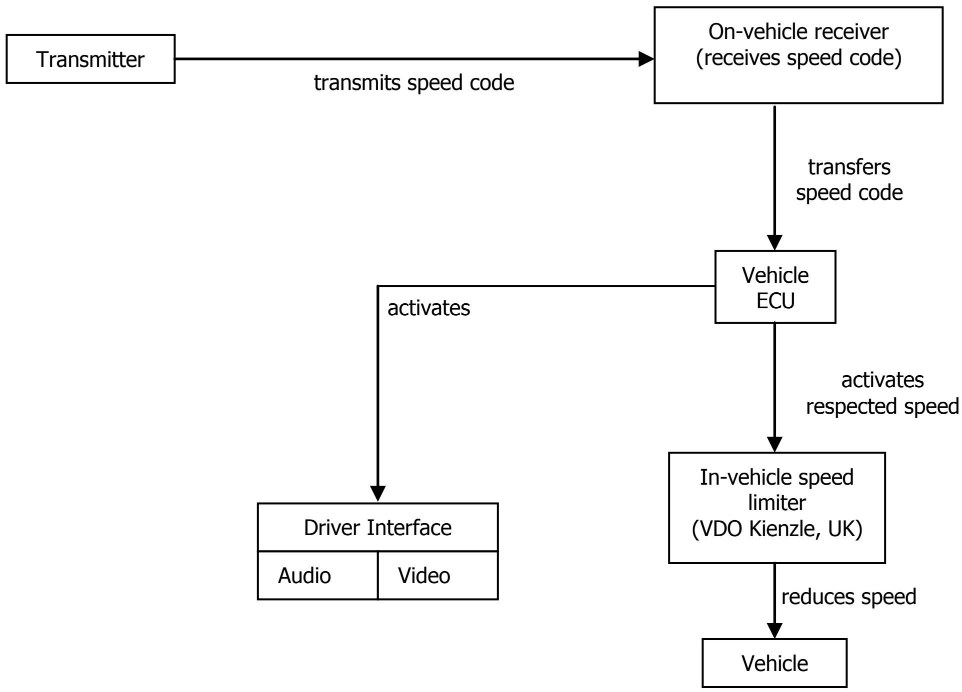


Figure 3-5: Block diagram of an Intelligent Remote Speed Adaptation for Vehicles

The block diagram of the system with the interaction of each elements is shown in Figure 3-5. This Intelligent Remote Speed Adaptation for vehicles consists of the following modules:

- Roadside Transmitter

  This is an off-the-shelf RF solutions transmitter that transmits the speed limit code of that area. It is a low power FM UHF radio transmitter on a small module and has a saw controlled wide band FM transmission.

- In-vehicle Receiver

  This is an off-the-shelf RF solutions UHF radio receiver that together with a matching transmitter forms a data link. This receiver is used to receive the speed code transmitted by the roadside beacon and activates the in-vehicle speed limiter device.

- System coding

  The transmitter and receiver modules have no internal digital coding/decoding thus allowing the flexibility to send many types of data. The Encoder and Decoder IC are required to give the system a high degree of protection from noise, neighbouring & interference systems. For this, off-the-shelf hardware modules are used. A HT12E (Holtek) is the encoder employed to send the speed codes to the transmitter, and a HT12D (Holtek) is the decoder used at the receiver to decode the received speed code. These encoders and decoders are used to demonstrate the beacon based speed control communication system. Due to its frequency of operation this setup is license free and easily available in the market.

- Circuit Interface

  A small circuitry was developed and introduced between the receiver and the in-vehicle speed limiter. Since the in-vehicle speed limiter needs 6V or higher to recognize a high signal and the receiver does not satisfy this condition, a level shifter interface is added in between to do the same.

- In-vehicle speed limiter device

  Modern engines used in both vehicles and static applications today have electronic throttle controls. Depending on the user requirements the engine speed can be controlled using an electronic speed control module for the throttle. For evaluation purposes, an in-vehicle speed limiter developed by VDO-Kienzle that allows the user to set the engine speed to the desired level was used.

It is intended for connection between an engine's electronic throttle control (e.g. throttle pedal) and its ECU to provide engine speed control and road speed control functions. There is no direct connection from the original throttle pedal and the ECU. When the vehicle is moving, its top speed will be limited (if configured) to a pre-programmed level. A lower vehicle speed can be selected by means of an interlock and the maximum engine speed can also be limited.

The speed limiter is a mechatronic sub system with the following functional and physical characteristics:

- It can interface up to 3 channels of throttle signals.
- 2 vehicle speed limits (minimum of 5 km/h).
- 1 top engine speed limit (min of 1, 500 RPM and max of 10, 000 RPM).
- Variable engine speed.
- 12V or 24V operation.
- Operating temperature ranging from – 40 °C to + 85 °C.

In its simplest mode of operation, when installed between a throttle pedal and an ECU, the in-vehicle speed limiter is constantly monitoring the throttle pedal output and replicating its own output signal. Its controller unit comprises of a main circuit board that holds all circuitry necessary to interface to individual vehicles/engines.

There are three status-in points. These general-purpose digital input signals give the in-vehicle speed limiter more flexibility when dealing with different types of user requirements (vehicles).

3.4.3 Vehicle-to-base communication

In the prototype architecture, there are two types of vehicle-to-base communication. The first is in the form of a hardware interface, and the second is the communication protocol that transmits data from the vehicle to the infrastructure (base network).

In section 3.4.2, the two prototype systems have been discussed. These systems are integrated together to illustrate the capability of a multiple ITS model. This was done using in-vehicle hardware interfaces, which are products of Dearborn Electronics, UK. Although these are off-the-shelf products, the firmware was modified, and software APIs were developed for this project.

3.4.3.a In-Vehicle Interface 1 (Gryphon)

Dearborn Electronics, (2001) states that the Gryphon is a hardware interface to all vehicle network protocols and connects to the network via the Ethernet port using TCP/IP. It is one of the most vital components is the vehicle network interface that allows multiple ITS systems to connect to it, process and distribute data for sharing.

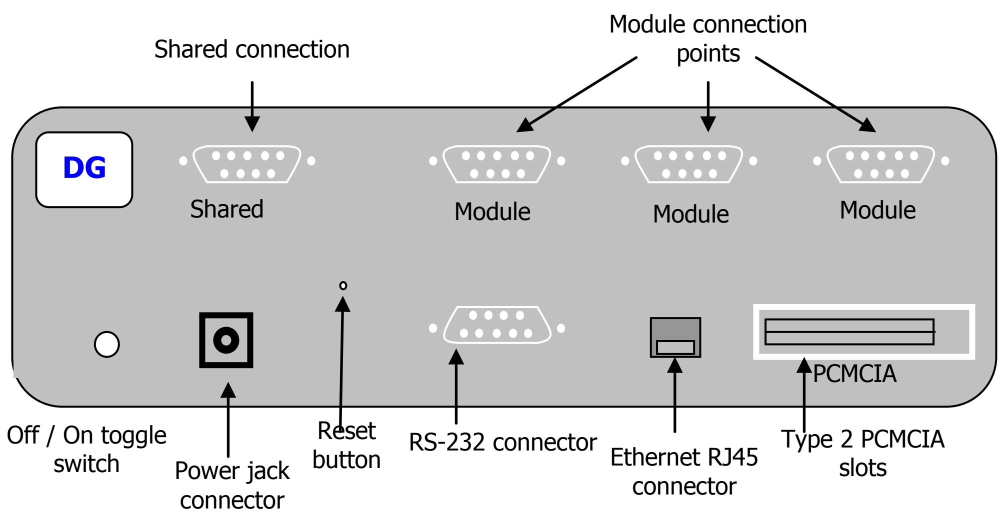


Figure 3-6: Rear view of the in-vehicle computer (Dearborn Electronics, UK)

As it supports multiple protocols, it reduces the need for redundant communication components. For example, the weigh-in-motion system that requires a remote communication system to transmit its data normally would have to have its own transceiver. Similarly, the speed limiter system would need another communication system for its data exchange. However, by integrating a single transceiver with the in-vehicle computer the device can be shared by both the systems.

3.4.3.b <u>In-Vehicle Interface 2 (UNAT)</u>

Dearborn Electronics, (2001) states that the UNAT is a hardware interface to all vehicle network protocols and connects to the network through a RS-232 port. It is programmed to accept signals from both enforcement systems, convert them to CAN messages and transmit them on the CAN bus. These messages are then made available on the CAN bus such that it can be accessed by any other ITS system on the vehicle if required. In order to do this it, the UNAT was placed upon the CAN network as a node. The dWIM system is connected to the analogue input, and the ISA receiver is connected to the digital input of the UNAT.

The UNAT is connected to the PC through the RS-232 port. A software Graphical User Interface (GUI) was developed to monitor these messages and present them in a user-friendly format. The details of the software are described in the following sections.

The in-vehicle hardware interface provides remote connectivity for multiplexed automation and automotive communication networks. Applications include diagnostics, monitoring and troubleshooting and other custom implementations. Two different hardware interfaces were used during the development of prototype architecture. The difference between Gryphon and UNAT is that Gryphon has a RS-232 port that can only be used for diagnostics. The UNAT is more versatile as it allows a bi-directional data transfer through its RS-232 port. It is also considerably smaller in size and acts as an interface that supports multiple protocols, hence, further into the research programme the UNAT replaced the Gryphon.

As the second level of communication, this research has used a wired RS-232 / Ethernet form of vehicle-to-base communication. However, data exchange between the vehicles and external agencies can be done using long or short-range wireless communication such as Bluetooth (for short-range vehicle-vehicle and vehicle-to-infrastructure applications) or Lower earth orbital satellite communications systems (for long-range vehicle-to-base station (or external agencies) applications. These various forms of wireless technologies form an excellent platform of future research and future development of the prototype architecture.

3.4.4 Base Network

This section discusses the various software elements that were specifically developed for the realisation of the integrated architecture and evaluation of the framework. These are the vehicle simulator, software APIs, the hardware interface firmware and a graphical user interface.

3.4.4.a Software API and user interface

ITS systems that can be plugged into the proposed framework generate (or can generate) any signal such as analogue, digital or even direct CAN vehicle messages. In this case, the dWIM generates analogue and ISA generates digital signals. As a part of the process first he analogue signals are converted into a digital signal and then all digital signals are converted into CAN messages. During the transmission and when receiving these signals/messages, the firmware/software API are designed to reject invalid (incorrect) signals/messages. In case there is a loss of signal/message the software would wait for the next valid signal. Once the signals/messages are received, the software performs the appropriate action. The software also maintains a feedback loop that allows it to continuously monitor for new signals/messages until a termination request is received or sent.

There were two separate software APIs and user interfaces developed specifically for this research. The first one was developed for the Gryphon, and the second one was developed for UNAT. The objectives of both interfaces were the same, however, the way they were connected to the remote PC differed. The Gryphon connects to the PC over TCP/IP via the Ethernet port, and the UNAT hardware interface uses RS-232 serial port communication protocol. The UNAT interface had direct digital I/Os which was an advantage over its former counterpart.

User interface for Gryphon

The Gryphon interface was developed using visual C++ and the Gryphon C++ libraries. The basic user interface, is shown in Figure 3-7, contains 6 operational buttons whose functionalities are discussed below. Additionally, there are 4 text boxes, 3 of which are used to display the output and 1 that allows the user to input the IP address of the Gryphon (the IP address may vary from unit to unit).

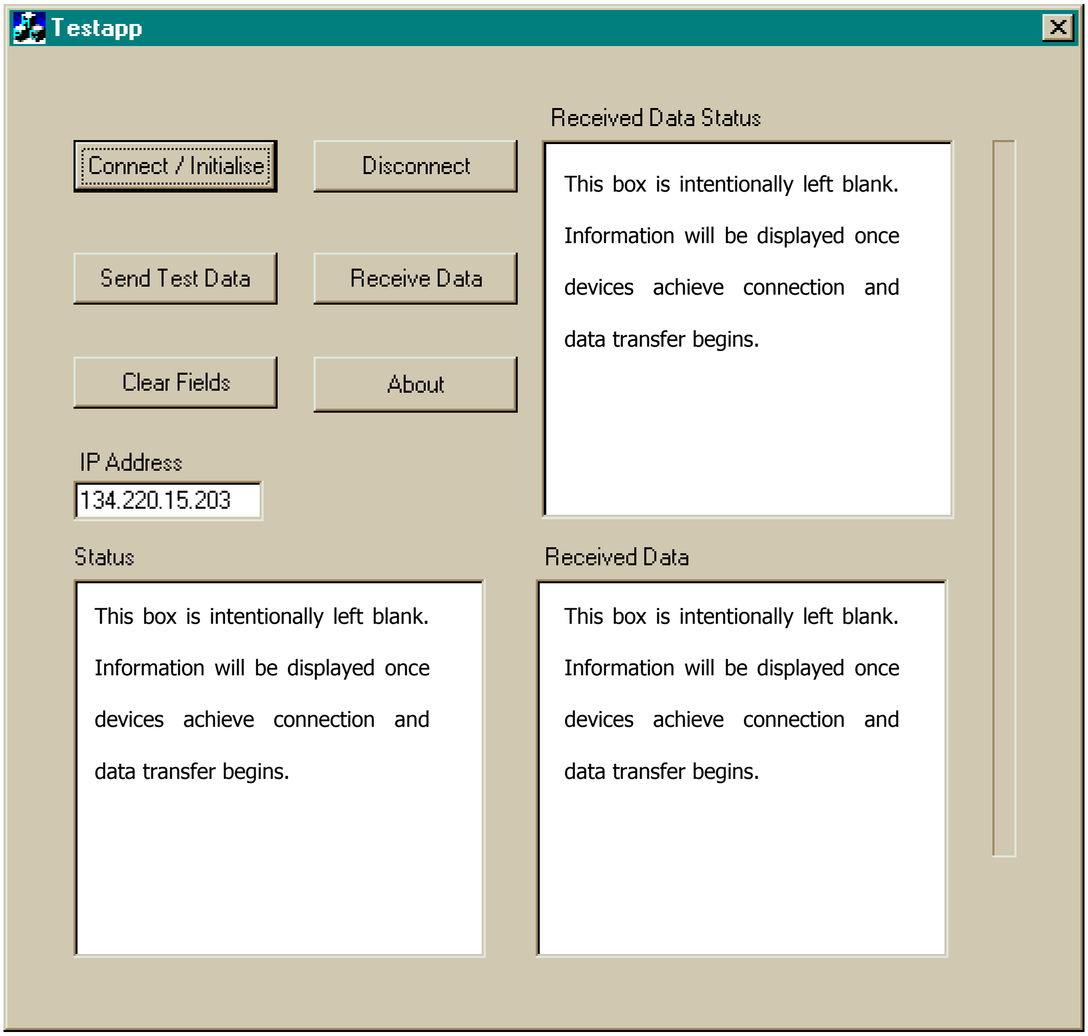


Figure 3-7: Before connecting to the Gryphon

The application on start-up does not have any information within the status windows. The first step is by entering the unique Gryphon's IP address. Using the Connect button, connection to the vehicle is done, and data exchange can be started. When connected, various parameters such as session status, device name, serial number, channel details can be seen. The core functionality to receive data on the CAN bus to which the Gryphon is connected as a node can also be achieved, in this case it is the ISA and dWIM data.

<u>User interface for UNAT</u>

The UNAT API and functionality is similar to the Gryphon's API. There are small differences in communication between the two. For the UNAT interface, entering an IP address is not required for connecting to the vehicle as it uses RS-232 connection. The data flow process methodology is illustrated in Figure 3-8.

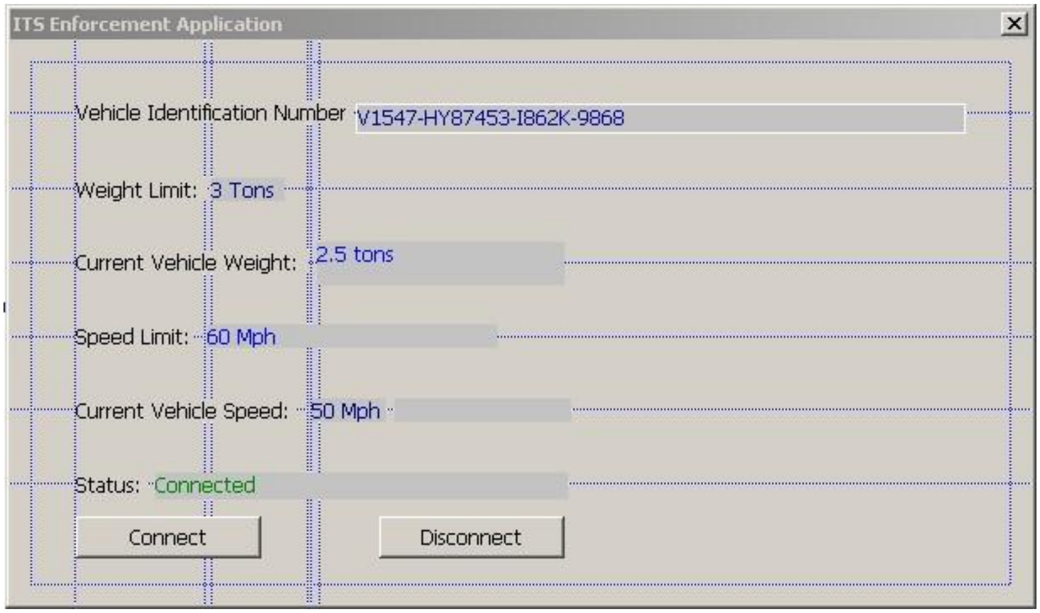


Figure 3-8: UNAT user interface screenshot

3.4.4.b <u>UNAT interface algorithm / firmware</u>

A firmware was developed to connect to the vehicle's bus, accept messages and broadcast them to the remote network. These messages included raw weight and speed data received from the dWIM and ISA systems respectively. To be able to use the data, it first needs to be converted into digital signals and then to CAN messages using software programming. This software module resides within the hardware interface as a part of its firmware. Since the firmware, and hardware interface used are proprietary to the manufacturing company it is not described in this report for confidentiality reasons. However, a data flow diagram to illustrate the algorithm methodology is shown in Figure 3-9.

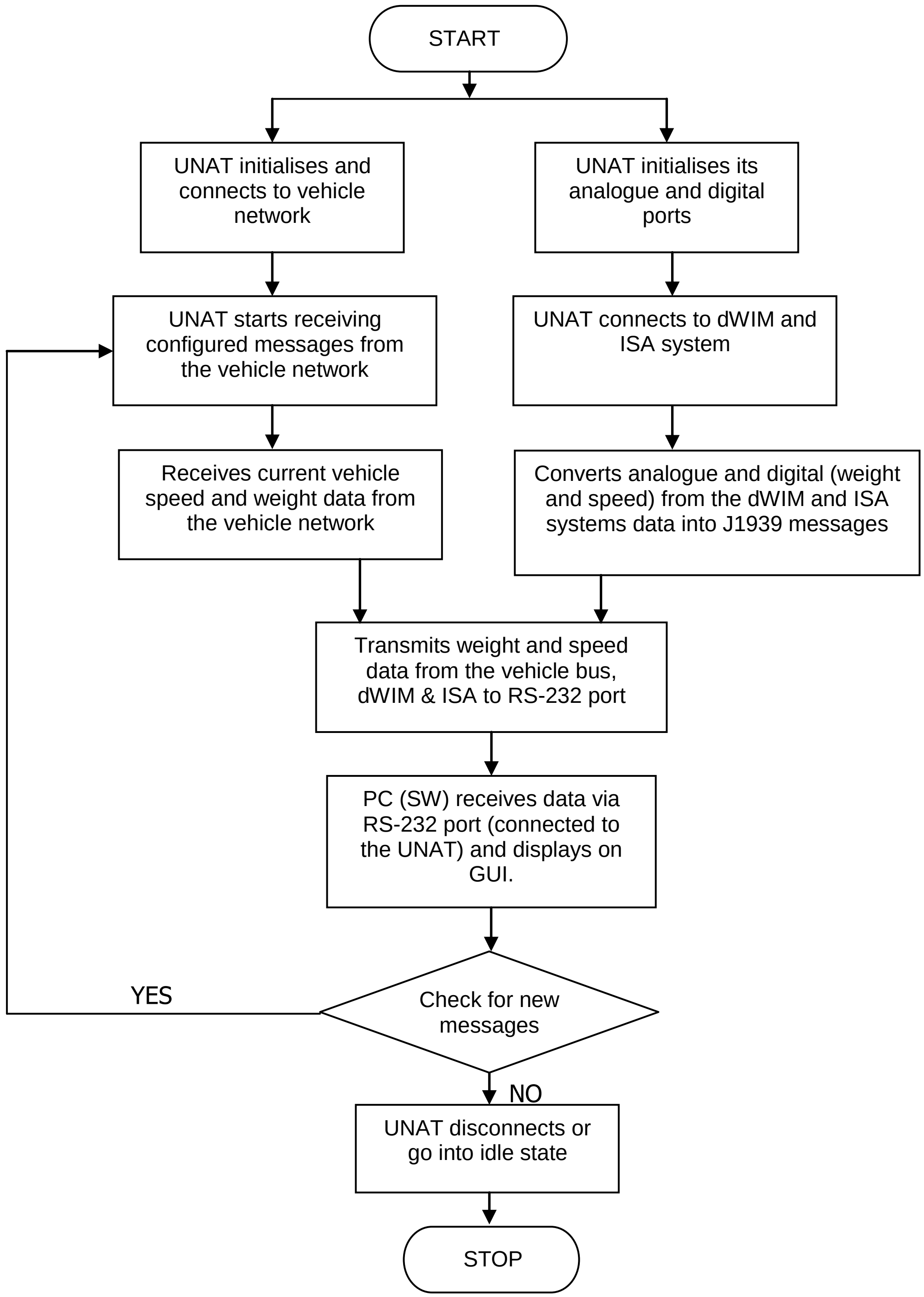


Figure 3-9: Data flow within the hardware interface

The UNAT initialises itself and connects to the vehicle network. The CAN messages from various vehicle systems are available on the bus, and upon completing the connection, these messages are received by the UNAT. The firmware is programmed such that at the time of connecting to the bus, it also initialises the analogue and digital ports, which are connected to the dWIM and ISA systems. Both systems have signals that are converted into CAN messages by the firmware and transmitted to the remote PC via the RS-232 port. The UNAT can be further programmed to filter messages in the vehicle if required; the other option would, however, be to filter them at the network.

3.5 Vehicle Simulator

This section presents the component of the architecture that was used to simulate the vehicle messages that are generated by various in-vehicle systems. This was developed as an evaluation step for the messaging algorithm design within the in-vehicle hardware interface. This was an integral part of the project as it helped to understand the technical feasibility and scope of the ITS systems developed and adapted for the framework.

The 2 ITS systems (dWIM and ISA) are simulated along with other vehicle ECUs, thus replicating a typical vehicle environment. These systems transmit/receive messages used to diagnose, monitor and control various vehicle parameters.

The description of message transmission protocols (CAN & RS-232) that are used as part of the integrated platform is attached in Appendix C.

3.5.1.a *Simulator Description*

CANoe (CAN open environment), is a comprehensive tool for CAN projects, that supports the entire development, planning and simulation of networked systems. This tool helps the user to plan, test, evaluate and develop complex modern automotive integrated electronics. Due to its flexibility and ability to simulate different ITS system parameters, CANoe is used as a tool to simulate vehicle messages. The simulation and development process of the system is done in two stages:

Stage 1: Requirement analysis and design of the networked system.

As a first step, various vehicle nodes were identified and enabled in the tool. This gave a clear layout of the vehicle system architecture. Each node has its specific functionality, based on which each node CAN messages were programmed in their respective message formats and baud rates.

The next step involved specifying the characteristics of the network nodes with regards to the input and output variables and messages to be received and transmitted. The simulation model designed (refer to Figure 3-10) is an event driven model with a procedural description of behaviour. The simulation model has a number of nodes that are sending / receiving messages on the CAN network. Certain nodes such as SpeedLimiter, UNAT, WeightControl react when they detect certain messages on the CAN network. The model illustrates how vehicle messages that are event driven react. This results in different messages, which can be, used as control variables for other systems on the vehicle CAN bus.

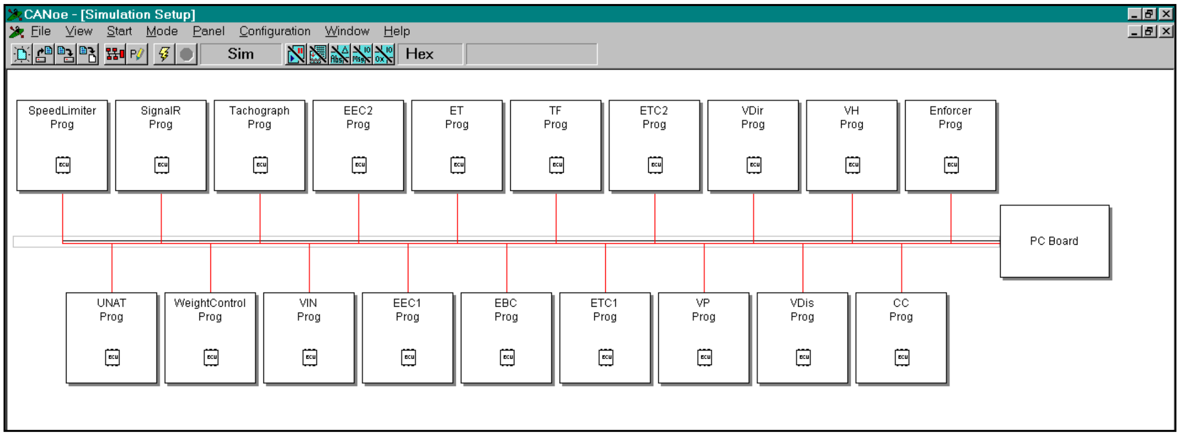


Figure 3-10: Simulation model

There are 18 nodes, representing different subsystems of a vehicle (Note: there are 18 nodes, and 15 systems since ISA is one system with 2 nodes, the in-vehicle interface is 1 node and monitoring enforcer program is 1 node). The following is the list of the 15 systems:

- Electronic Engine Controller 1
- Electronic Engine Controller 2
- Engine Temperature
- Electronic Brake Controller
- Wheel Speed Information
- Transmission Fluids
- Electronic Transmission Controller 1

- Electronic Transmission Controller 2
- Vehicle Position
- Cruise Control /Vehicle Speed
- Vehicle Direction
- Vehicle Distance
- Vehicle Hours
- dynamic Weigh-in-motion
- Intelligent speed adaptation system

Stage 2: Implementation of components with simulation of the remainder of the bus.

Model generation: For the distribution of functions over network nodes (ITS or vehicle parameters), the necessary vehicle messages, and the individual parameters of each node that form part of the simulation model, are configured at the start of the model development. Other appropriate data, like the *environment variables* (e.g. switch settings, sensor signals, output signals) are also stated and implemented.

Simulation: On the basis of this, CANoe then simulates and analyses the data communications between the individual network nodes and their environment.

Other vehicle nodes (rest-bus simulator): For this research, CANoe is used as a rest-bus simulator. The environment variables of the real network nodes are processed in the simulation system.

Each of the systems (mentioned above) is setup to transmit messages on the bus at specific intervals, and this message transmission is based on the SAE J1939 standard. The UNAT is also connected to the bus (J1939 network) and simulates the reception of the messages.

The results obtained from this simulation is discussed in the following chapter and the source code is listed in Appendix F.

3.6 Summary

This chapter discusses the theoretical and technical approaches followed for the development of the integrated ITS architecture. The novelty of the framework is to show how the fragmented ITS and prototype architecture enforcement systems can be integrated together and more importantly communicate with the infrastructure. The objective of this framework is to make the infrastructure a part of the vehicle environment, or rather more importantly make the vehicle and infrastructure parts of a unified framework.

While, Toulminet, G. (2008) discusses project COOPERS' vision, in which vehicles can communicate with infrastructure; however the aim of the infrastructure is to gather traffic information and provide it to the vehicles. The aim of the proposed architecture is to integrate ITS together for such applications but also allow the use of powerful algorithms at the infrastructure to improve traffic performance.

The complete system was also simulated using a tool that helped in evaluating the interaction of various vehicle parameters with multiple systems working together.

The dWIM system (Phase 1 & 2) discussed in the former sections was mainly developed as a replica of an ITS system to generate the necessary weight messages. The other ITS system (ISA) was developed using off-the-shelf hardware to generate speed messages.

Applications, validation and benefits of this framework are further discussed in chapter 5 where a novel traffic improvement algorithm (TIA) is developed and simulated to show the benefits this framework could offer.

In the next chapter, the validation of the framework is presented with data and information gathered integrating the two ITS systems and infrastructure.

Chapter 4 : Validation of the Integrated Framework

4.1 Introduction

In the previous chapter, the components of the conceptual framework and prototype integrated architecture were presented. In this chapter, the operation of the two ITS systems as a part of the framework are validated.

This is done in a series of functional steps and incremental architecture starting from the validation of the technical feasibility of the integrated system using complete vehicle simulation (Table 3-1). This is followed by replacing simulated components with physical systems, and finally conducting real-time evaluation.

4.2 Validating the framework in a simulated environment

The simulation of the framework is done using a tool called CANoe (which is used during automotive systems research and development). CANoe simulates the vehicle network by generating various system messages (CAN). The objective of this simulation of the framework is to understand the behaviour and responses of the ITS systems individually and when integrated together. This pre-development step gives an illustration of a functional vehicle and the message behaviour due it operation. A screenshot of the CANoe setup is shown in Figure 4-1.

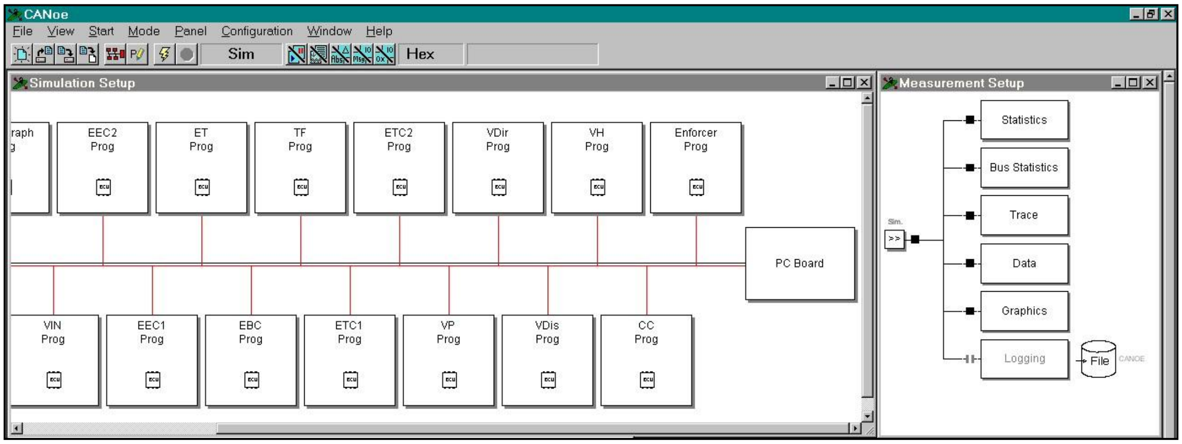


Figure 4-1: Complete system layout

The simulator setup is composed of test systems, including two enforcement ITS systems (dWIM and ISA). In Figure 4-1, it can be seen that each node of the setup represents a vehicle system. These systems were programmed to transmit messages as they would in a typical vehicle environment. The in-vehicle interface of the framework is placed as a node.

The output of the CANoe vehicle simulation is sent to a weight and speed simulation application. This application and GUI was developed using Visual Basic.

The simulator generates messages under two ways: the first are cyclic messages that are generated every n^{th} second repeatedly, and the second way is an event driven message which is generated manually using keystrokes. For the different scenarios that are discussed later in the chapter, the following pre-programmed keystrokes are used:

Chapter 4: Validation of the Integrated Framework

Keystrokes & Scenarios of Project Simulation

Keystrokes

Basic vehicle control

‘a’ - Accelerates.

‘b’ – Brakes.

Speed control

‘0’ – activates the 0 mph speed transmitter.

‘3’ – activates the 30 mph speed transmitter.

‘4’ – activates the 40 mph speed transmitter.

‘7’ – activates the 70 mph speed transmitter.

‘x’ – deactivates all speed transmitters.

Speed Scenarios

‘g’ – activates traffic control scenario.

‘h’ – activates over speeding scenario.

Error Signal

‘e’ – simulates an error / no signal.

Weight control

‘i’ – activates the overweight scenario.

‘o’ – activates the weight loss scenario.

‘p’ – activates the weight gain scenario.

Trigger

‘t’ - Request for information from the vehicle.

On this key press, the following messages are made available on the CAN network.

- Electronic Engine Controller 1
- Vehicle Direction
- Vehicle Distance
- Vehicle Hours

The remaining tests messages that are transmitted periodically are based on the SAE J1939 – 1x, 2x & 71 specification.

- J1939-1x – defines the transmission medium (cable, shielding), connectors, as well as the approved baud rate.
- J1939-21 – describes the basic data transmission mechanisms. Among other things, these are the structure of the CAN identifier and of the data bytes, definition of the transport protocols, the targeted request of information, and confirmation with the help of acknowledge.
- J1939-71 – describes the application layer and defines all parameters and parameter groups.

These messages are listed below:

- Electronic Engine Controller 2 transmission repetitive rate: 50 ms

▪ Engine Temperature	transmission repetitive rate: 1000 ms
▪ Electronic Brake Controller	transmission repetitive rate: 100 ms
▪ Wheel Speed Information	transmission repetitive rate: 100 ms
▪ Transmission Fluids	transmission repetitive rate: 1000 ms
▪ Electronic Transmission Controller 1	transmission repetitive rate: 10 ms
▪ Electronic Transmission Controller 2	transmission repetitive rate: 100 ms
▪ Vehicle Position	transmission repetitive rate: 5000 ms
▪ Cruise Control /Vehicle Speed	transmission repetitive rate: 100 ms

Figure 4-3 shows the traffic on the bus with details like data frames, error frames and load on the bus.

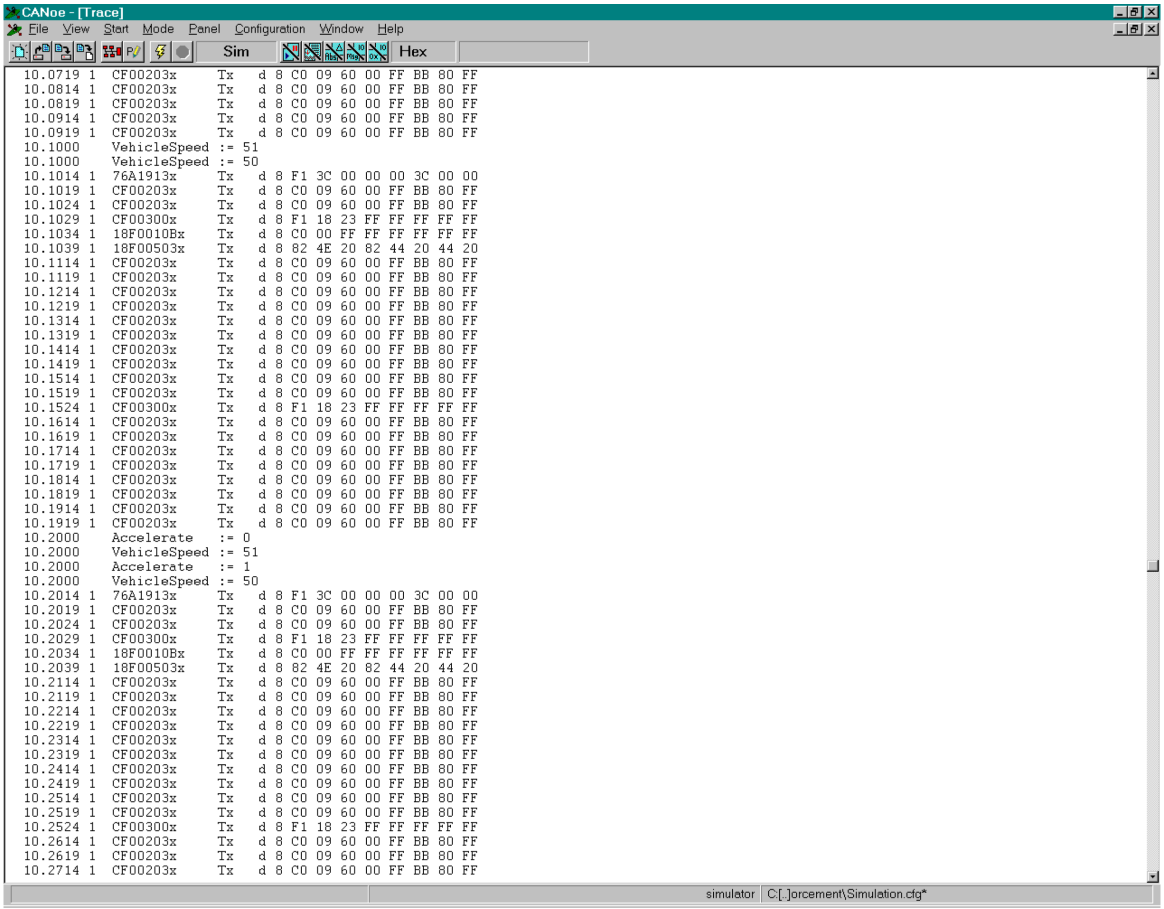


Figure 4-2: CAN Messages Trace

- The first column indicates the time when the message was transmitted
- The second column is the channel (as the system may have more than 1 monitoring channels) on which it was received
- The third column indicates the message identifier

- The fourth column indicates if it was transmitted or received. In this case all are shown as Tx as all nodes were programmed to send out messages and none were programmed to receive
- The fifth column indicates the data of the message

Based on the inputs (from CANoe) the weight / speed simulator displayed the relevant messages on the GUI.

Conclusions: By placing the framework in a simulated environment as discussed, the following is achieved:

- The setup gives a clear illustration on how both vehicle and ITS systems interact in an integrated environment, this forms a base for understanding how the framework would react to real-time systems,
- All vehicle messages exchanged can be analysed, and the system can be tested for fault tolerances (Figure 4-3) and successful data exchanges.

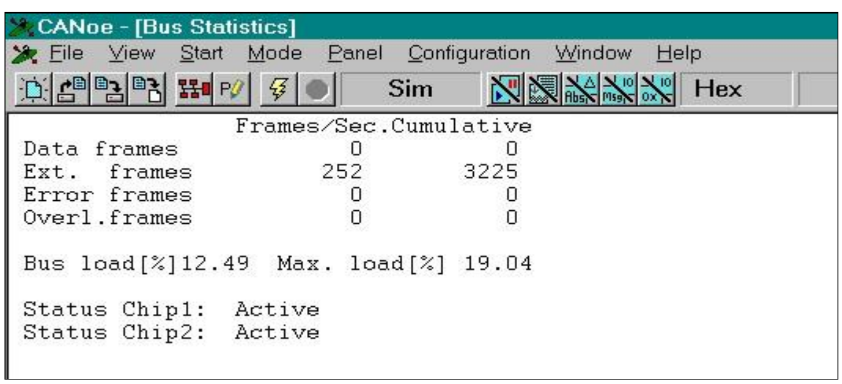


Figure 4-3: Bus statistics

4.3 Validating the framework in a laboratory environment

Upon successful validation of the integrated framework within a simulated environment, the two simulated ITS nodes were replaced with bench level system setups.

4.3.1 dWIM system

The dWIM system is one of the ITS systems used as a prototype component within the developed integrated architecture. The dWIM was first tested as a standalone system and was later integrated with ISA in order to evaluate its operation in an integrated environment.

The dWIM system was also tested in two stages. In the first stage, all tests were done using a table top strain-gauge. The operating process is started by clicking on the *Connect/Initialise* button. This initialises the Gryphon (vehicle hardware interface installed on the vehicle) and a communication link is established. The status of the connection and details of the interface is seen in the "Status" window in Figure 4-4.

When the *Receive Data* button is clicked the weight message (in this case filtered for dWIM) is seen in the "Received Data" window Figure 4-4. The message is split into two parts the first line indicates the last three data bytes of the message and the second line shows the interpretation of the message. In this case, the data received indicates that the vehicle has *0 kg* weight (). The other message details can be seen in the "Received Data Status" window this is the time stamp and frame stamp.

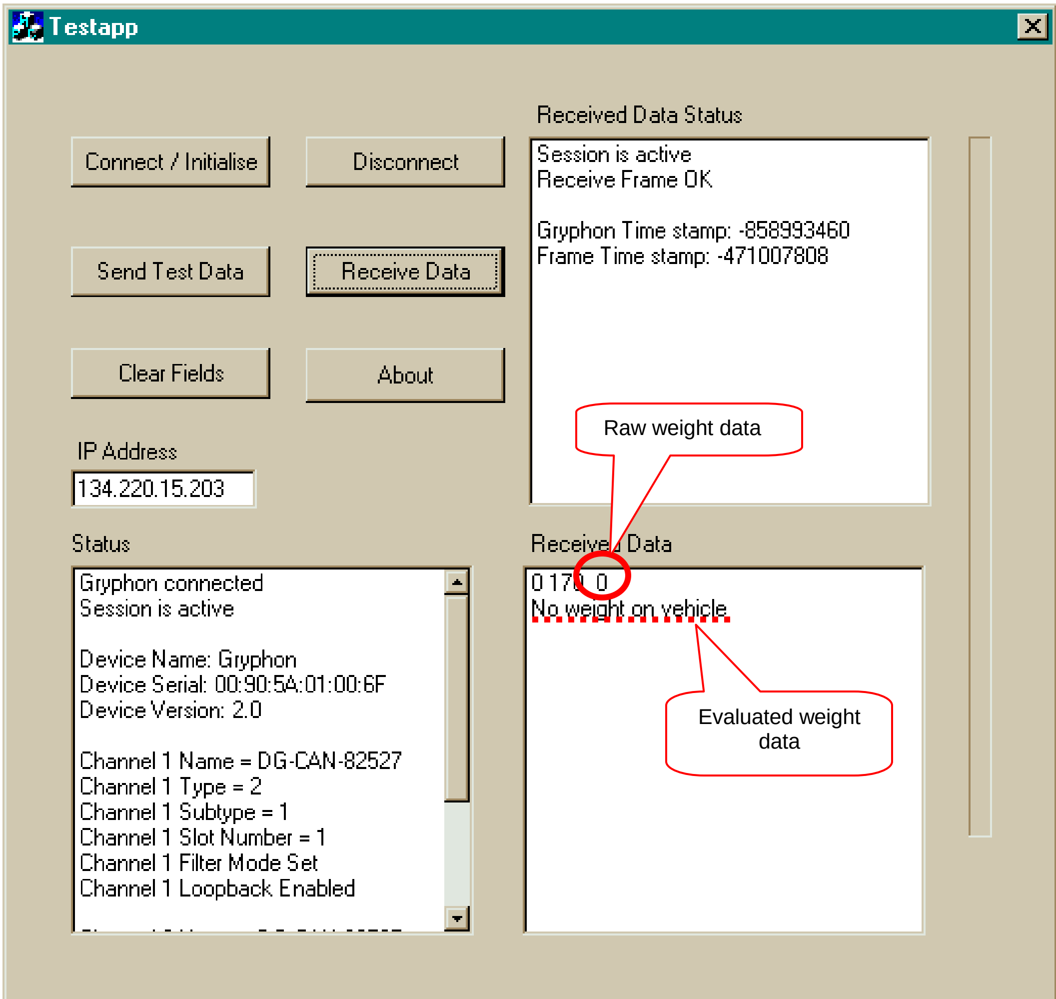


Figure 4-4: With 0kg weight

Upon adding some weight to the vehicle, the weight data changes accordingly. This change is reflected and seen in the "Received Data" window (Figure 4-5), where the weight is now 5 tonne. This weight value is simulated by programming a 3kg weight to show 5 tonne weight.

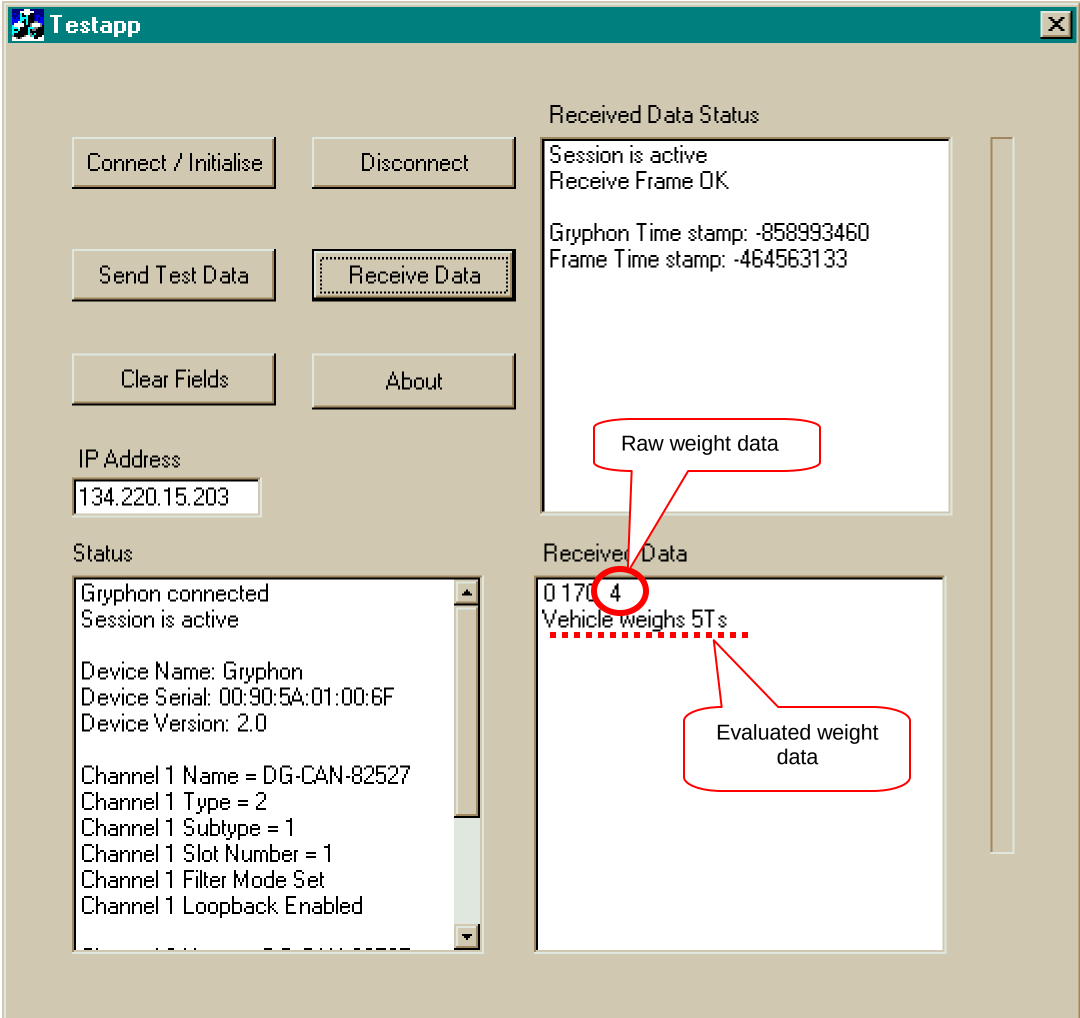


Figure 4-5: With 5 tonne weight

Similarly in Figure 4-6 a 5 kg weight indicates 7 tonne of weight on the vehicle.

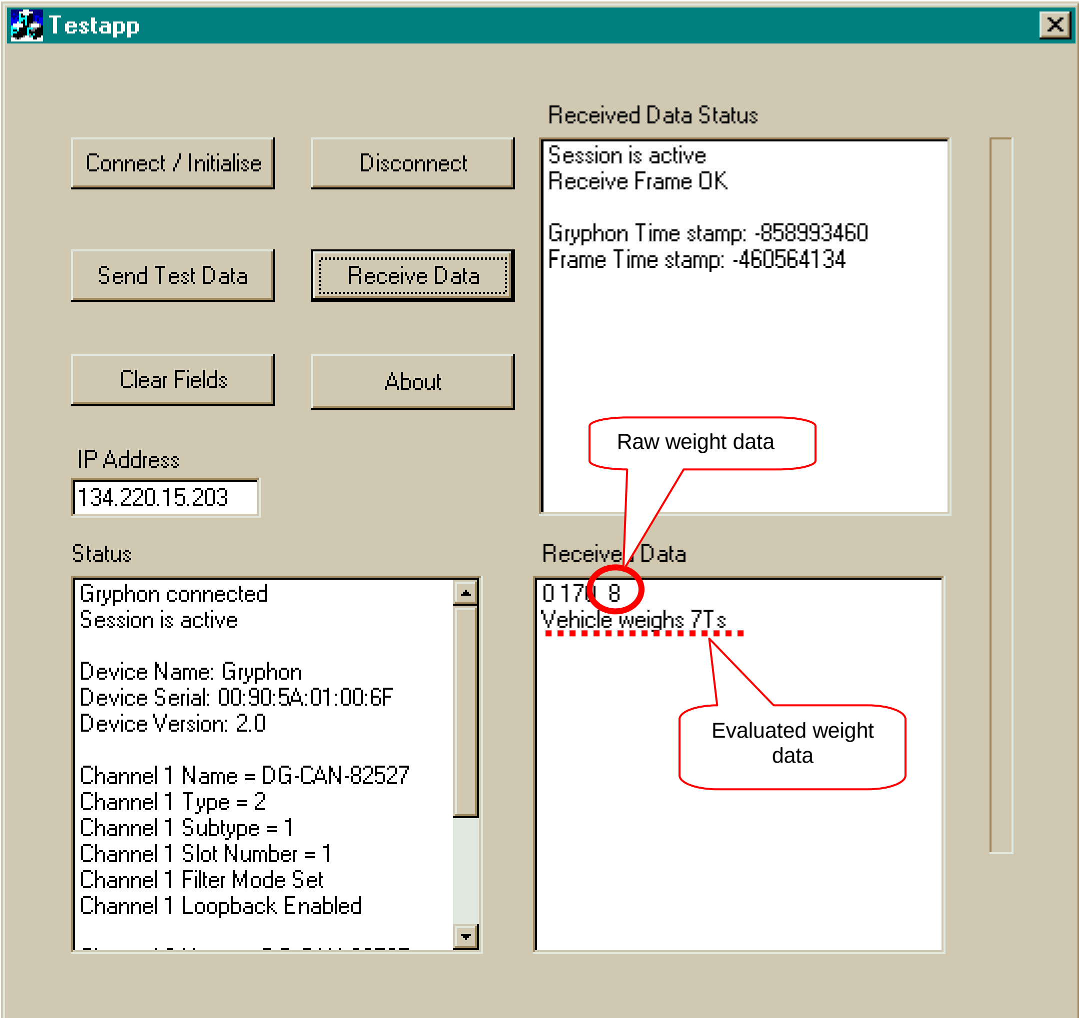


Figure 4-6: With 7 tonne weight

The sensitivity recorded from the strain gauge which was used for the tabletop setup is shown in Table 4-1 (a). In order to record these values, various graded weight bars were added on the plate. The graded weight bars are uncalibrated and close to the weight marked on them. In order to use the nearest to weight specified, each bar was applied to the system. Hence, this was done 5 times (for each bar), and the most stable value from them was identified. These initial recordings are indicated in Table 4-1 (a). Following this, the "nearest to weight" bars were identified and these are indicated in Table 4-1 (b). The final values that were used and recoded from the "stable weights" are recorded in Table 4-1 (c). These values can be analysed using graphs.

	TABLE (a) Initial readings							
Bar	Bar Weight y (kgs)	Voltage					Average voltage x (mv)	Maximum variance
		x 1 (mv)	x 2 (mv)	x 3 (mv)	x 4 (mv)	x 5 (mv)		
Bar 1	0.1	1.2	1.2	1.2	1.5	1.3	1.28	0.22
Bar 2	0.1	1.5	1.3	1.5	1.5	1.2	1.4	0.2
Bar 3	0.1	1.3	1.4	1.4	1.4	1.4	1.38	0.08
Bar 4	0.2	2.3	2.4	2.5	2.5	2.2	2.38	0.18
Bar 5	1	11.1	9.3	10.6	9.2	10.9	10.22	1.02
Bar 6	1	7.1	8	7.8	7.2	8.1	7.64	0.54
Bar 7	1	7.1	8.3	7.8	6.5	7.9	7.52	1.02
Bar 8	2	16	14.1	16.6	14.7	13.5	14.98	1.62
Bar 9	2.5	18.9	20	19.1	18.9	24.4	20.26	4.14
Bar 10	3	22.1	22.1	23.3	20.5	25.9	22.78	3.12
Bar 11	3.5	24.8	24.7	26.7	20.6	27.7	24.9	4.3
Bar 12	5	76	69.1	76.9	64.8	74.1	72.18	7.38

	TABLE (b) Stable weights readings							
Bar	**Bar Weight**	**Voltage**					**Average voltage**	**Maximum**
	y (kgs)	x 1 (mv)	x 2 (mv)	x 3 (mv)	X 4 (mv)	x 5 (mv)	x (mv)	variance
Bar 3	0.1	1.3	1.4	1.4	1.4	1.4	1.38	0.08
Bar 4	0.2	2.3	2.4	2.5	2.5	2.2	2.38	0.18
Bar 5	1	11.1	9.3	10.6	9.2	10.9	10.22	1.02
Bar 8	2	16	14.1	16.6	14.7	13.5	14.98	1.62
Bar 9	2.5	18.9	20	19.1	18.9	24.4	20.26	4.14
Bar 10	3	22.1	22.1	23.3	20.5	25.9	22.78	3.12
Bar 11	3.5	24.8	24.7	26.7	20.6	27.7	24.9	4.3
Bar 12	5	76	69.1	76.9	64.8	74.1	72.18	7.38

	TABLE(c) Final Value			
Bar	Bar Weight	Voltage	Maximum	Range
	y (kgs)	x (mv)	variance	(plus and minus)
Bar 3	0.1	1.38	0.08	1.30 < 1.38 < 1.46
Bar 4	0.2	2.38	0.18	2.20 < 2.38 < 2.56
Bar 5	1	10.22	1.02	9.20 < 10.22 < 11.24
Bar 8	2	14.98	1.62	13.6 < 14.98 < 16.6
Bar 9	2.5	20.26	4.14	16.12 < 20.26 < 24.4
Bar 10	3	22.78	3.12	19.66 < 22.78 < 25.9
Bar 11	3.5	24.9	4.3	20.6 < 24.9 < 29.9
Bar 12	5	72.18	7.38	64.8 < 72.18 < 79.56
	10	100	For Graph reference only	

Note: y=mx+c, assuming c=0 then y=mx. Taking the most appropriate (stable) value of x & y implies m = y/x = 72.5

Table 4-1: Comparison values of the Strain Gauge Sensitivity.

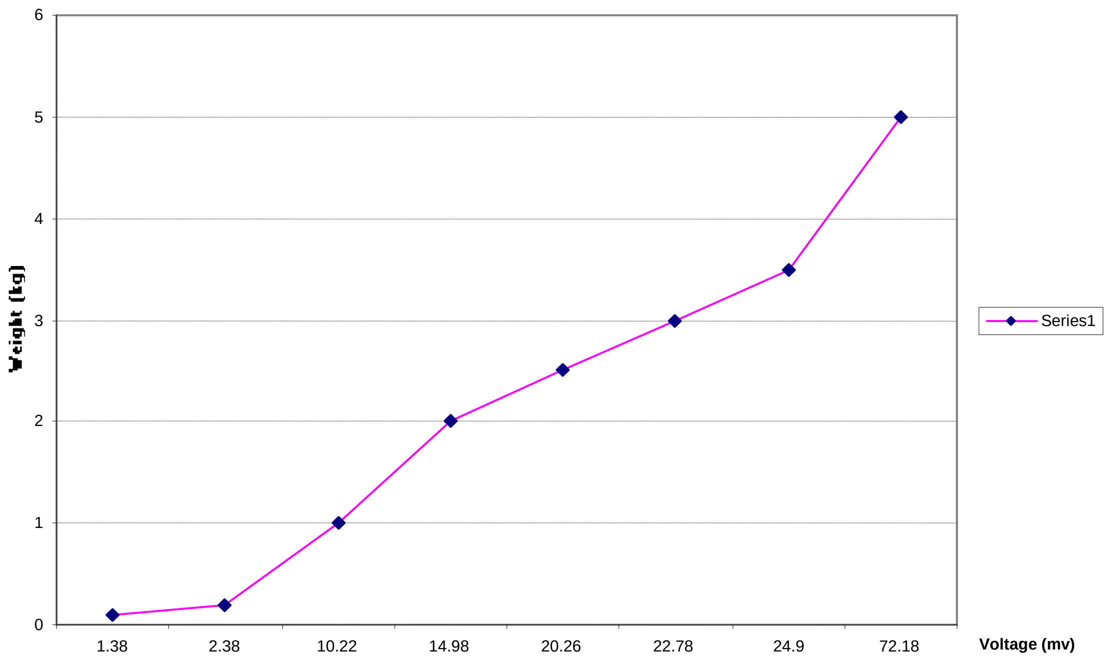


Figure 4-7: Strain Gauge Sensitivity Graph.

Figure 4-7 indicates the strain gauge sensitivity curve showing how with the increase in weight there is a proportionate increase in voltage (mv).

The weights used in the lab setup ranged from 100 gm to 5 kg. In the Table 4-2, weight is maintained in kilograms, but voltage is converted from millivolt to volt. Hence, for example if the weight on the strain gauge is 5 kg then the corresponding voltage value would be 0.6 volt. This voltage is then read and converted into a CAN message by the UNAT, which in turn is analysed by the application (on the PC) to show the weight on the sensor.

Sheet 1		
Weight (kg)	*Weight (tonne)*	*Output Voltage (volt)*
X	*X*	**Y**
0	*0*	0
0.1	*0.0001*	0.01
0.2	*0.0002*	0.02
1	*0.001*	0.09
2	*0.002*	0.1
3.5	*0.0035*	0.14
5	*0.005*	0.6

Table 4-2: Strain Gauge Weight Analysis

In the second stage of evaluation and in order to improve the performance of the dWIM system, the strain gauge sensor was replaced by industrial weight sensors that could handle heavier weights. The hardware interface was also replaced by UNAT which performed similar functions as the Gryphon but used RS-232 as a mode of communicating with the base network (infrastructure). The industrial weight sensor readings are shown in Table 4-3.

Intercomp Weight Analysis - Sheet 3		
Weight (tonne)	*Data Byte 2 reading (Hexadecimal)*	*Data Byte 2 reading (Decimal)*
X		**Y**
0	0E	14
3	0F	15
6.6	11	17
7	12	18

Table 4-3: Load sensor weight analysis

Due to the specification of the industrial sensors, the readings obtained were not in volts but in hexadecimal value, which were acceptable to the hardware interface. These corresponding readings were converted to CAN messages and were transmitted to the network PC. The data flow algorithm is shown in Appendix B. The graphical user interface (GUI) at the base network can display the appropriate vehicle weight based on the information received from the vehicle is shown in Figure 4-8.

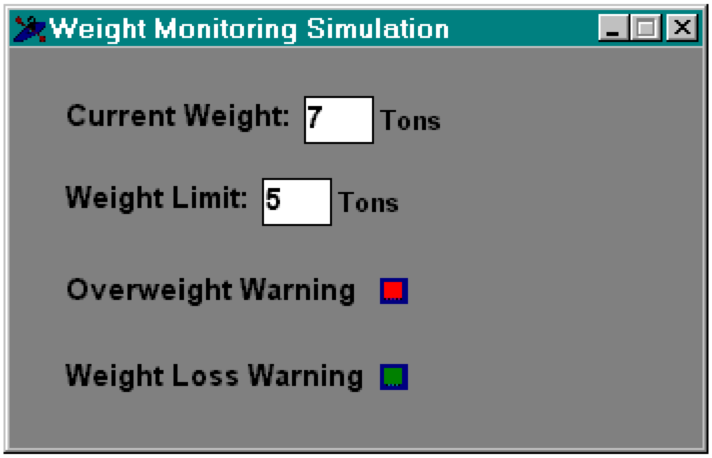


Figure 4-8: Weight Monitoring GUI

4.3.1.a *<u>dWIM system algorithm</u>*

The process of how the dWIM system presents the weight information at the base network consists of three steps:

- Step 1: generating the raw weight signal
- Step 2: converting this into CAN messages
- Step3: receiving and decoding the weight information at the base network

These processes are encoded within the software based on an algorithm as shown in Figure 4-9.

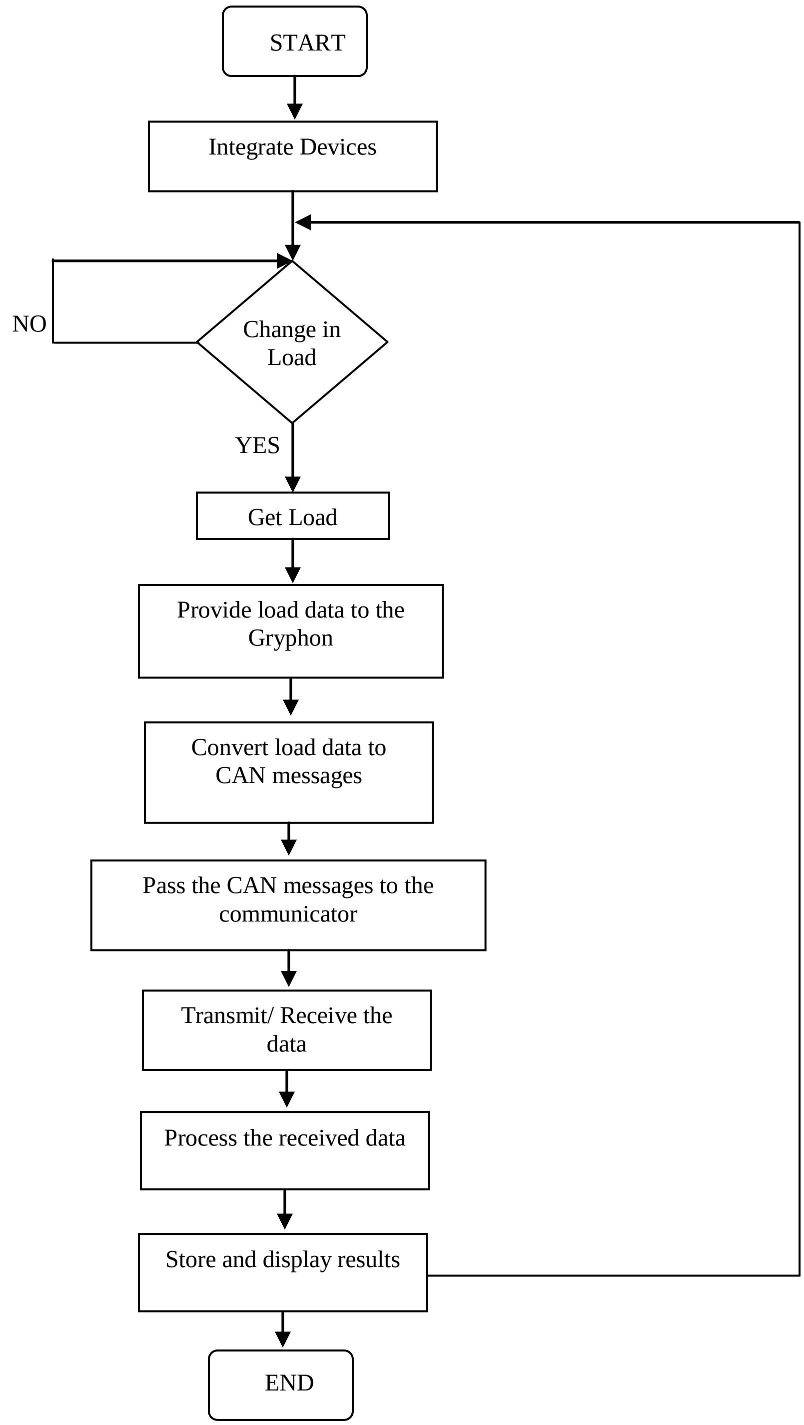


Figure 4-9: dWIM algorithm

Conclusions: This setup shows how analogue weight information, obtained from weight sensors, is converted into vehicle messages and received by infrastructure. As the first step, analogue weight data (in the form of resistance) is converted into a voltage. This voltage (and its change due to weight change) is converted into CAN messages and transmitted to the infrastructure. At the infrastructure end, each received CAN message is decoded, and weight information is presented.

4.3.2 ISA system

The second ITS system adapted/developed to be used within the integrated framework is a beacon based ISA system. This system was evaluated initially (without the dWIM system) as a standalone system before integrating it to the complete framework.

Step 1: For this evaluation ISA transmitters (that transmit speed limits) were installed on a street light pole and the receiver was installed in a truck on the top of the cabinet's roof (Figure 4-10).

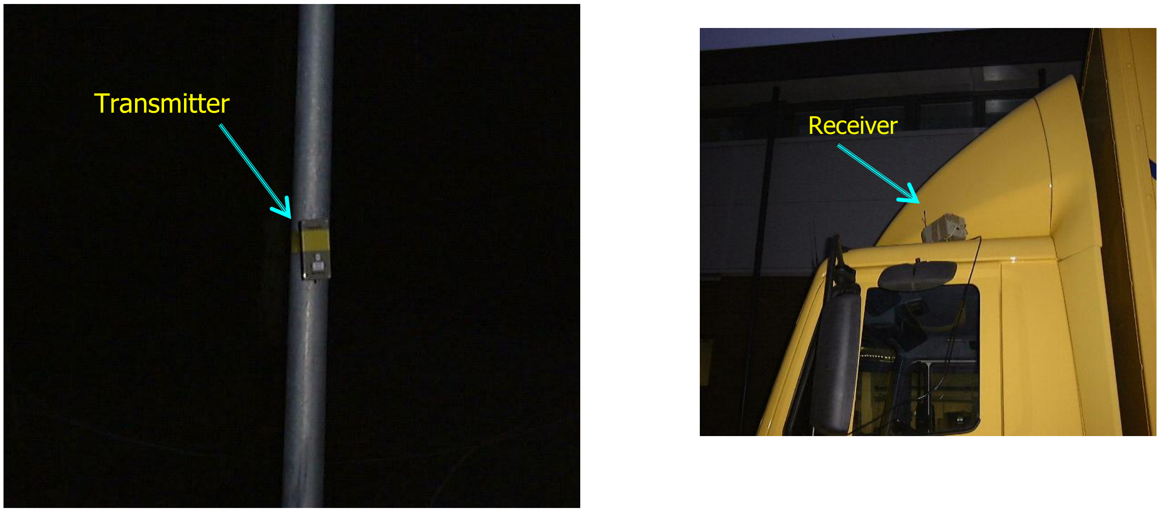


Figure 4-10: Pictures of transmitter and receiver

Since this was a lab based evaluation, speed limiting functionality was monitored on a PC running the ISA algorithm and application. The receiver was connected to a laptop that runs the simulator application. The application alerts the user when the vehicle comes within the zone of the speed limit beacons.

Each transmitter beacons the speed limit code, which is received by the receiver when it comes in the respected transmitter range. On receiving a digital speed signal, the receiver transfers it to the PC through 4 dedicated data lines of the parallel port. With 4 different codes pre-programmed with respect to the speed limits (0mph, 30 mph, 40 mph & 70 mph), the simulator would then react to the limits. The speed limit is programmed in a digital binary code as shown in Table 4-4: Binary speed codes.

Speed Limit (mph)	Data 1	Data 2	Data 3	Data 4
0	0	1	0	1
30	0	1	1	0
40	1	0	1	0
70	1	0	0	1

Table 4-4: Binary speed codes

The ISA receiver is connected to the laptop PC through the parallel port cable. The above described codes are transmitted to the simulator (laptop) through this parallel port. The connections to the ISA system and PC were made as shown in Figure 4-11.

ISA Receiver		PC Parallel port
Data line 1	↔	Pin 11
Data line 2	↔	Pin 12
Ground	↔	Pin 18
Data line 3	↔	Pin 13
Data line 4	↔	Pin 15

Figure 4-11: ISA Receiver / Simulator pin-out connection

The speed limit signals received from the receiver is transferred to the simulator that displays the speed limit based depending on the code received.

Step 2: After the successful evaluation of data messages from Step 1, the next step was to integrate the ISA system and use it in real-time with an in-vehicle speed limiter. This had a similar setup as the simulator test but in this test, the PC simulator was replaced by working in-vehicle speed limiter and a vehicle. The speed limiter beacons were installed on the street light poles with the receiver installed inside the car. The car's speed limiter was connected to the receiver, and when the car came within the range of the speed limit beacons its speed decreased to the transmitted speed limit.

Conclusions:

Step 1: This setup achieved one of the objectives i.e. evaluate how vehicle speed control could be done, adapting one of the ISA technologies (beacon based) where speed limits are transmitted by the infrastructure, and received, processed and applied to the vehicle.

Step 2: This setup evaluated the ISA system in a vehicle environment and illustrated the vehicle behaviour and reaction in a speed control zone.. This is a standalone ISA system test in a vehicle that leads to the next step of integrating it as a part of the conceptual framework.

4.4 Validating the framework in a real-time environment

In the next step, the two ITS systems dWIM and ISA were integrated as a part of the proposed architecture. Both types of the dWIM system (strain gauge and load cell based dWIM) were tested using separate setups. The first setup comprised of the strain gauge sensor and ISA; while the second setup employed a heavier weight sensor and ISA. Both the ITS systems were connected to one hardware interface and evaluated as one integrated environment.

The data exchange between the vehicle and base network was done after processing raw signal data at firmware and software level. This processing is based on the algorithm shown in Figure 4-12.

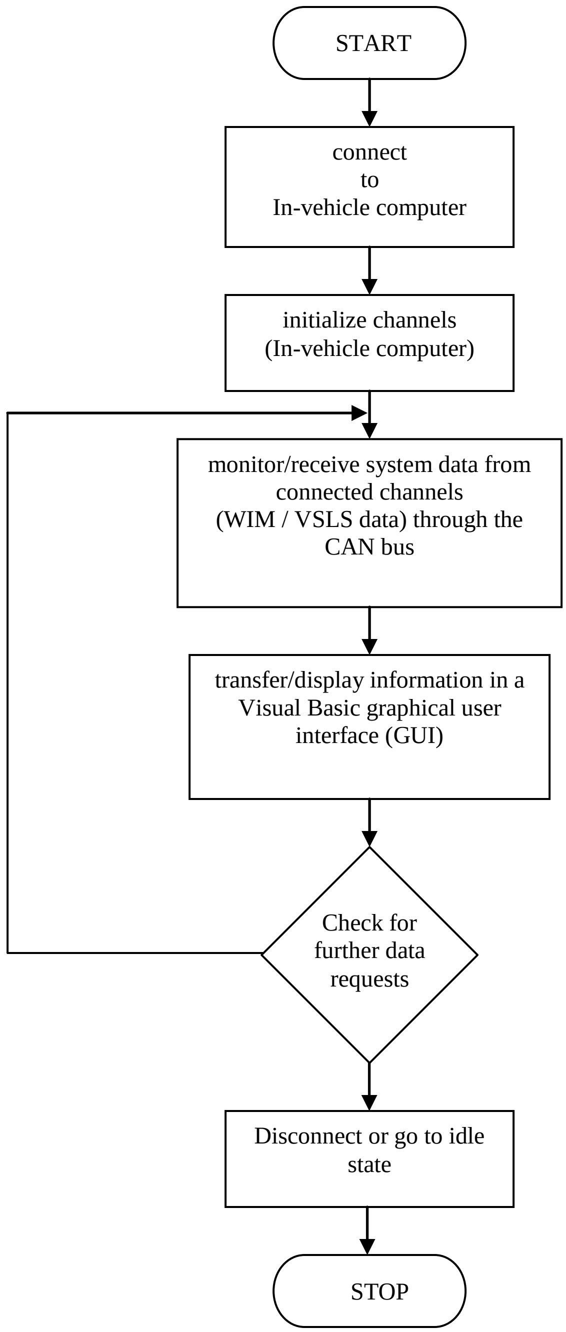


Figure 4-12: vehicle-base data transfer algorithm

Figure 4-13 to Figure 4-21 illustrate the validation setup of the working system. The results and readings obtained at the time of the demonstration are the same as the ones shown in the section 4.3.

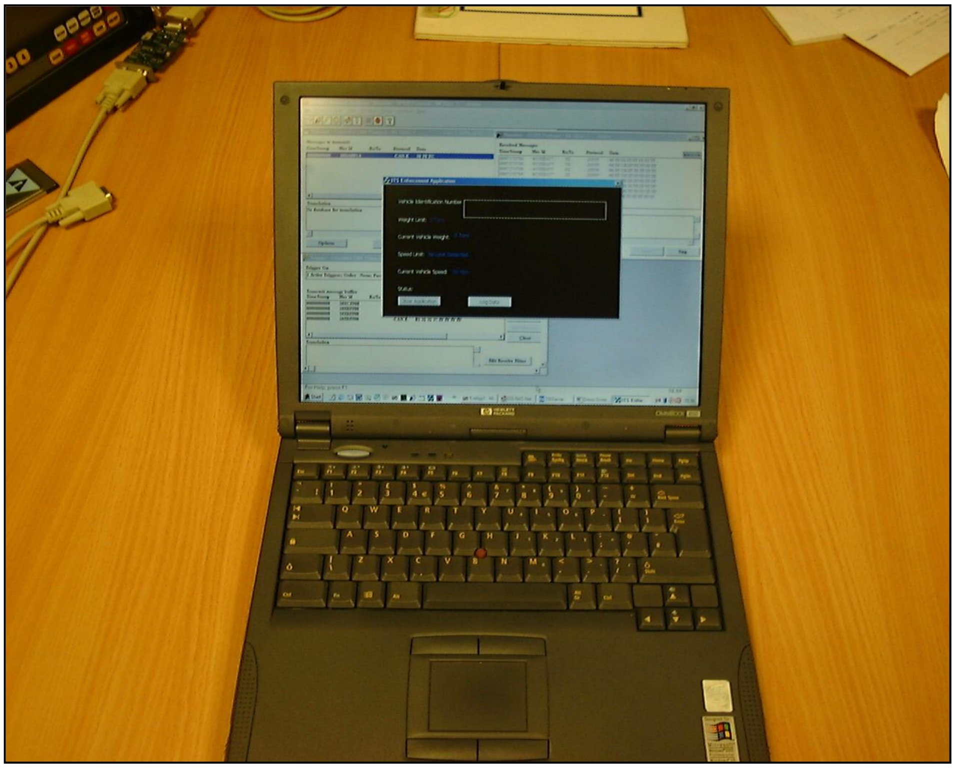


Figure 4-13: Data monitoring PC

The picture in Figure 4-13 above illustrates the laptop PC used to monitor the data received from the two enforcement systems. The objective of this PC is to simulate the base network environment. Hence the PC was used to run the dWIM & ISA algorithms and software APIs. It was also used to simulate and transmit other dynamic vehicle parameters. This was done evaluate the integrated framework with real-time messages such that both systems and infrastructure work together in one environment and illustrate the benefits of the framework.

Figure 4-14: Gryphon

The picture in Figure 4-14 above illustrates the Gryphon interface, which was used to send the dynamic vehicle parameters to simulate the vehicle under real time conditions and the picture in Figure 4-15 shows the 4 transmitters that transmit the speed limit signals and the receivers, which received these signals. The receiver that has 4 digital outputs was connected to the UNAT.

Figure 4-15: Speed limiter communication system

Figure 4-16: Strain gauge based dWIM system

The picture in Figure 4-16 above illustrates the strain gauge based sensor system as described phase 1.

Figure 4-17: Intercomp loadcell based dWIM system

The picture in Figure 4-17 above shows the Intercomp (loadcell) based sensor system as described in phase 2.

Figure 4-18: Strain gauge with 0kg weight

Figure 4-18 above shows the reading as ‘0 kg’ when there was no weight on the sensor.

Figure 4-19: Strain gauge with 3½ kg weight and in 30 mph speed limit

Figure 4-19 show the weight reading and a speed limit of 30 mph since the 30 mph speed limiter was activated.

Figure 4-20 below shows the reading as 0 kg with the loadcell sensor connected instead of the strain gauge sensor. With the strain gauge system, 0-5 kg weight data could be generated, and for higher weight information, the loadcell sensor was used.

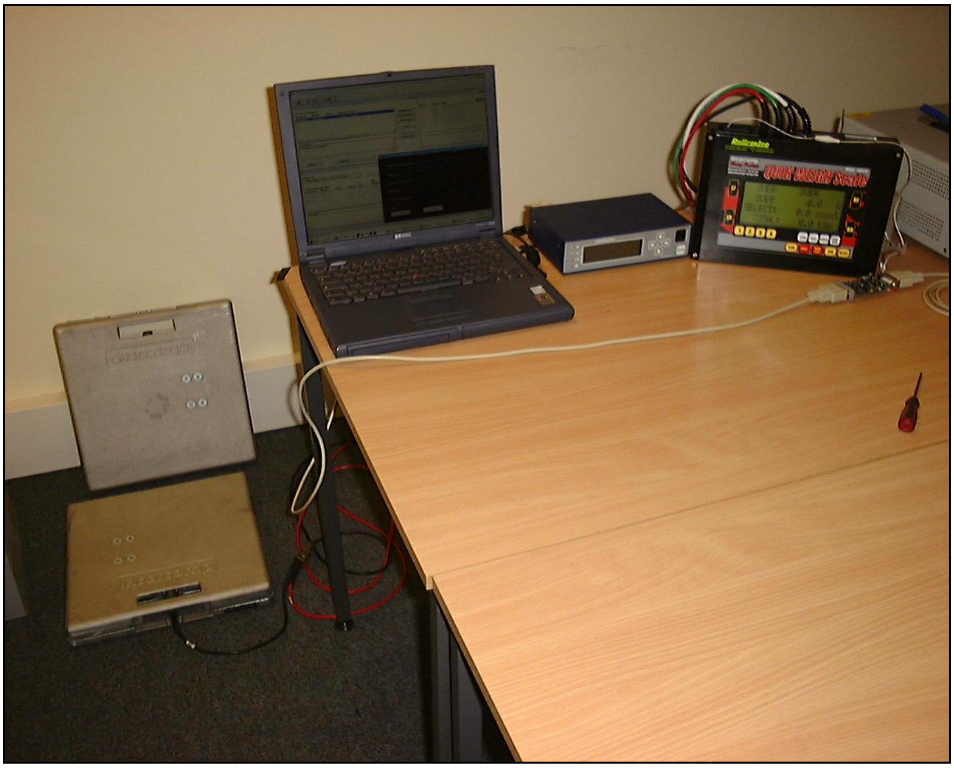


Figure 4-20: Intercomp loadcell system with 0kg weight

Figure 4-21: Intercomp loadcell system with 22½ kg weight

Figure 4-21 above shows the dWIM with heavier weights which was limited to 5kg using the earlier strain gauge system. The change of weighing systems did not have any effect on the system setup but increased the capacity of the system.

Conclusions: The following objectives were achieved when validating the framework in a real-time environment:

- each ITS system (dWIM and ISA) sent their relevant signals data messages out (weight and speed limit)

- these signals were converted to data messages and sent to the PC (simulated base network) where they were decoded and presented.
- As a part of framework validation, data integrity and interference was also achieved

4.5 Summary

The systems described in the previous sections were developed independently at different times during the project. The ISA communication components that include speed limit transmitters and a receiver were the first system to be developed, and tested with simulator software installed on a laptop. After laboratory evaluation and validation, (Section 4.3) the work proceeded to the next stage that involved the vehicle level validation.

For the development, of a dWIM system two setups were arranged, a tabletop strain gauge sensor and a load cell sensor. The strain gauge sensor was a table top system and was used for weights 0-5 kg whilst the load cell system was used for heavier weights.

Both prototype systems i.e. dWIM and ISA were developed and validated separately (Sections 4.3.1 & 4.3.2). Upon receiving satisfactory results (Section 4.4) from the prototype systems, they were integrated together based on the model discussed in chapter 3. However, before this stage a similar setup was simulated using CANoe (Section 4.2). This tool simulated a typical vehicle CAN bus that transmitted their data on the vehicle bus based upon the SAE J1939 standard. There were 18 vehicle nodes that were simulated and two prototype ITS systems ISA and dWIM were also a part of the simulation model. This simulator assisted in monitoring systems behaviour independently, in an integrated environment and to predict their behaviour in real time testing.

Chapter 5 : Framework Application Case Study

5.1 Introduction

In the previous chapters the concept, evaluation and validation of an integrated framework was presented. This chapter presents a case study on the application of the developed framework for the improvement of traffic conditions on a real transport network. For the realisation of an ISA-based speed harmonisation platform a novel algorithm, named Traffic Improvement Algorithm (TIA) has been designed to demonstrate the benefits of this integrated framework. The algorithm employs machine learning techniques, such as Fuzzy Logic and Genetic Algorithms (GA) in order to minimise the travel time over a 10km stretch of the M6 motorway in the UK. Fuzzy logic inference systems map an input space to an output space by using a set of linguistic rules, fuzzy membership functions and fuzzy logic operations. A fuzzy logic system (FLS) can be defined as the nonlinear mapping of an input data set to a scalar output data.

5.2 Application of ISA for speed harmonisation

As stated in the literature review chapter, ISA systems were initially introduced as safety-oriented ITS. Heydecker, B.G. (2011), Carlson, R.C. (2011) and Jianlong Z. (2006) discuss the current ISA applications on motorways advise, or in some cases enforce, speed limits in order to allow drivers to slow down when approaching traffic streams with considerably lower travel speeds. However, recent research findings demonstrated that one of the effects of variable speed limits is the improvement of traffic flows due to the alleviation of problems such as excessive stop-and-go occurrences.

For the development of the proposed TIA, fuzzy logic was selected due to its inherent characteristic of good performance under non-linear conditions. Nonlinearity of traffic optimisation parameters (eg. flow, density, speeds) under variable speed limits (VSL) was evidenced in the work by Carlson, R.C. (2010). In addition, the authors identified variations in the fundamental speed-density-flow relationships under different speeds limits. Carlson, R.C. (2010), states that current research indicates on the application of VSL for traffic flow improvements is using control theory on a macroscopic simulation environment as the optimisation mechanism. The proposed FLS-GA approach is applied to a micro-simulation environment and has the following characteristics:

- The stochastic behaviour of the model makes it suitable in situations where uncertainties between input and output parameters exist. As stated above, this is the case for traffic engineering parameters when variable speed limits are in operation.
- The GA that is used for the optimisation of the rule set of the FLS allows the model to be trained using different fitness parameters and therefore expands the range of applications that the model can support. For example, the research work that was presented above uses the total travel time of all vehicles on the network as the optimisation parameter. Microsimulation environments allow the use of instantaneous emission models for estimating the levels of different pollutants that are emitted from individual vehicles. These emission levels can be the fitness parameters of the GA and therefore amend the behaviour of the proposed model.

The different components of the proposed algorithm, together with its application and evaluation are described in the following sections.

5.2.1 Fuzzy Logic Fundamentals

A FLS consists of four main parts: fuzzifier, rules, inference engine, and defuzzifier. These components and the general architecture of a FLS is shown in Figure 5-1.

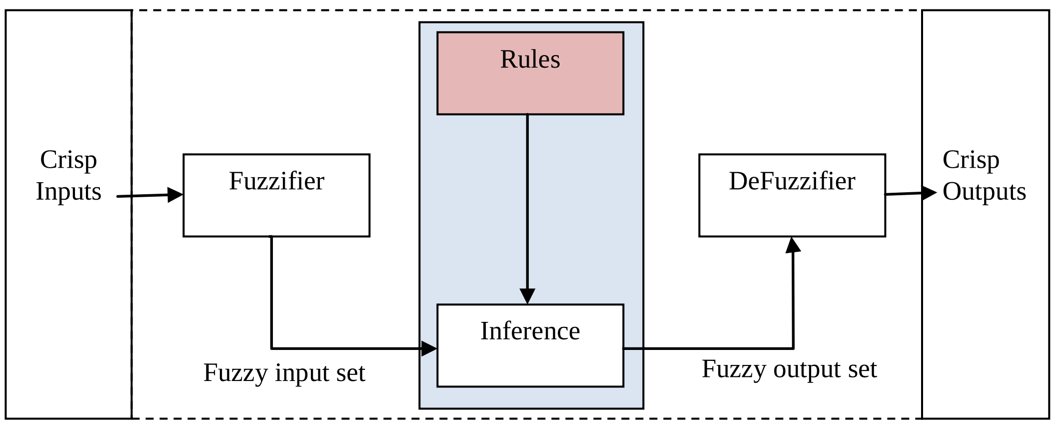


Figure 5-1: A Fuzzy Logic System

The operation of fuzzy logic system consists of the following stages. Firstly, a crisp set of input data are gathered and converted to a fuzzy set using fuzzy linguistic variables, fuzzy linguistic terms and membership functions. This step is known as fuzzification. Afterwards, an inference is made based on a set of rules. Lastly, the resulting fuzzy output is mapped to a crisp output using the membership functions, in the defuzzification step.

The terms commonly used in a fuzzy system are defined as below:

Linguistic Variables

Linguistic variables are the input or output variables of the system whose values are words or sentences from a natural language, instead of numerical values. A linguistic variable is generally decomposed into a set of linguistic terms.

Membership Functions

Membership functions are used in the fuzzification and defuzzification steps of a FLS, to map the nonfuzzy input values to fuzzy linguistic terms and vice-versa. A membership function is used to quantify a linguistic term. There are different forms of membership functions such as triangular, trapezoidal, piecewise linear, Gaussian, or singleton.The type of the membership function can be context dependent and it is generally chosen arbitrarily according to the user experience

Fuzzy Rules

In a FLS, a rule base is constructed to control the output variable. A fuzzy rule is an IF-THEN rule with one or more conditions and a conclusion.

Fuzzy Set Operations

The evaluation of the fuzzy rules and the combination of the results of the individual rules are performed using fuzzy set operations. After evaluating the result of each rule, these results should be combined to obtain an aggregated outcome. This process is called inference. The results of individual rules can be combined in different ways.

De-fuzzification

After the inference step, the overall output is a fuzzy value. This linguistic output should be de-fuzzified to obtain a final crisp output. This is the purpose of the de-fuzzifier component of a FLS. De-fuzzification is performed according to the membership function of the output variable.

5.3 Traffic improvement algorithm

5.3.1 Overview

The architecture of the traffic improvement algorithm can be seen in Figure 5-2 below.

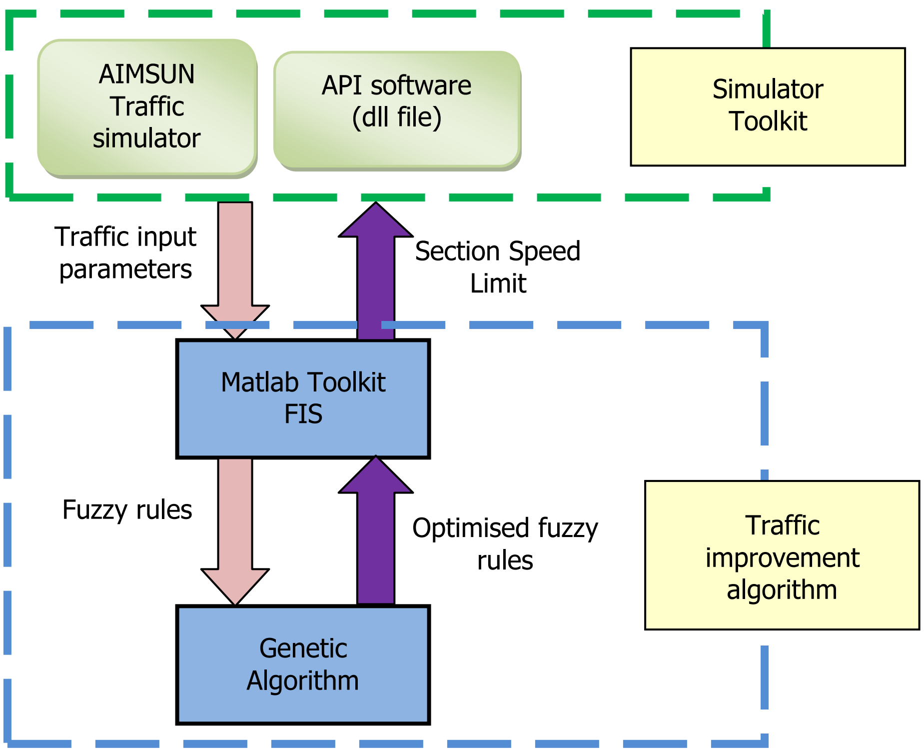


Figure 5-2: Traffic improvement simulator overview

The traffic parameters for each section of the motorway are generated by the AIMSUN microscopic simulator and are passed onto the fuzzy system in predefined time intervals. These traffic parameters form the input to the FLS and are used to generate the desired speed for each section. The derived speed limit of each section (output of the FLS) is then sent back to the traffic simulator and is applied to the current traffic. This is repeated continuously for the course of the simulation.

Improvements on the network can be achieved if the fuzzy rules can lead to section speed limits that optimise a particular parameter from the simulation. For the optimisation of the fuzzy rule set a GA has been developed. The GA uses a specific traffic parameter for adjusting the rules in order to achieve better results. This traffic parameter is defined as Total Travel Time / Total Distance Travel.

5.3.2 Generation of traffic data using AIMSUN

The transport network that was used as part of the research was modelled using the Aimsun microscopic simulator The model was composed of the South East-bound direction of the M6 network (between 8 and 6) and a traffic demand that was generated using real traffic data supplied by the Highways Agency (HA). The traffic demand used, allowed for the simulation of a two-hour period between 7:00am to 9:00am, thus it included peak-hour traffic. In order to create a disruption on the traffic flow an accident at the last section of the modelled network was simulated. The accident was initiated at 7:20am, it lasted for 30 minutes and it blocked two of the three running lanes of the motorway. A layout of the developed network can be seen in Figure 5-3.

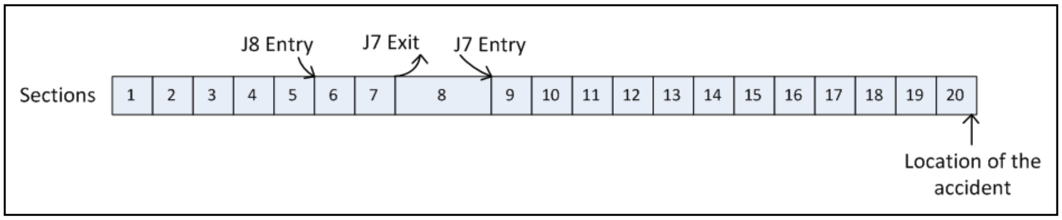


Figure 5-3: AIMSUN network

Each of the 20 sections has a length of 500m, apart from Sections 5 and 7 which have length of 432m and 244m respectively. This was done to accommodate the entry/exit ramps that join the motorway. The 500m length was used since this is the typical gap between successive gantries equipped with variable message sign on managed motorways.

Two control cases that represent the limits (in terms of the total travel time) of the proposed algorithm were defined. The first (lower limit) is derived from the operation of the network under normal conditions, while the second (upper limit) is derived from the operation of the network with the occurrence of the accident. Both of these control cases do not involve operation of variable speed limits. The new model will be evaluated under the "accident occurs" conditions. It is hypothesised that the FLS-GA algorithm cannot produce a better output, than the lower limit. In addition, for the performance of the proposed model to be classified as acceptable the output produced must be lower than that of the upper limit.

The aggregated network statistics (for the 2-hour period) for the two control scenarios can be seen in Table 5-4 below.

Parameter	Simulation with no traffic accident	Simulation with traffic accident	Unit
Speed	75.35	22.61	km/h
Density	18.95	45.77	veh/km
Flow	6546	5786.5	veh/h
Delay Time	14.67	88.57	sec/km
Mean Queue Length	20.16	675.14	vehs
Number of Stops	0.14	0.86	avg/veh/km
Stop Time	1.43	51.29	sec/km
Distance travelled	114731.5	101220.67	km
Travel time	1568.72	3423.25	h

Table 5-1: Simulated network statistics

As it can be seen from the above parametric data, there is a clear worsening of the conditions in the scenario where the accident occurs. Based on the description of the limits provided above, the developed model will be evaluated against a lower limit of 1568.72h/114731.5km (0.0137) and an upper limit of 3423.25h/101220.67km (0.0338) total travel time. Figure 5-4 shows the fluctuations of the three fundamental traffic engineering parameters, (density, flow and speed) in five-minute intervals, for the two simulation scenarios.

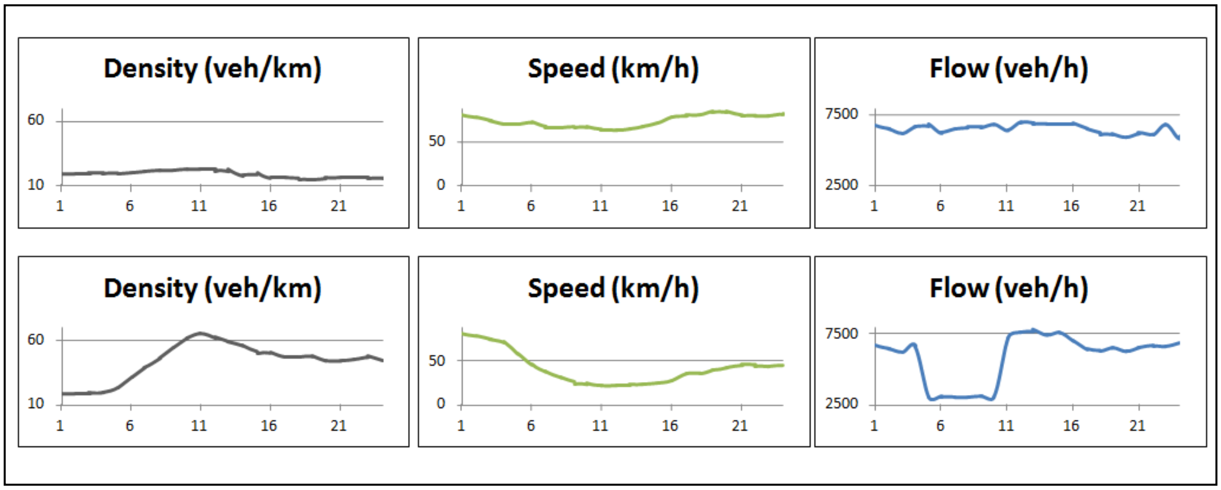


Figure 5-4: Fluctuations of input parameters

As in the case of the aggregated data the conditions on the second scenario worsen between the 4th (7:20am) and 5th (7:25am) 5-minute interval. This is the interval after the accident and therefore the results are normal.

As it can be seen in Figure 5-2, the Aimsun simulator communicates with the fuzzy system through a Dynamically Linked Library (dll) that was developed as part of the project. The C++ source code of the library can be found in Appendix F. Furthermore, screenshots from the Aimsun model can be seen in Appendix C.

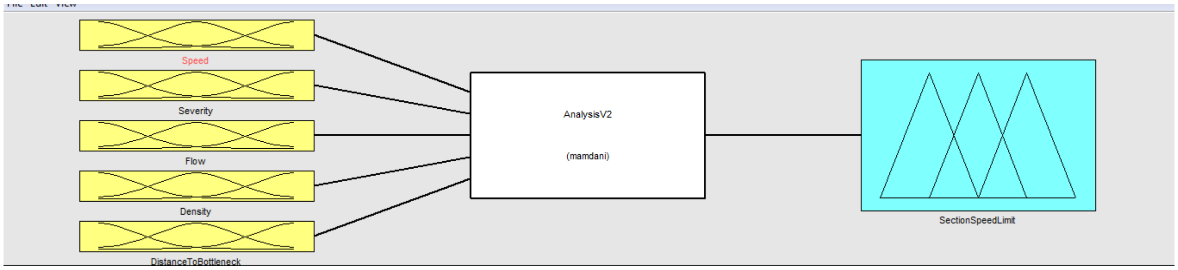


Figure 5-5: Traffic improvement FIS

The TIA uses 5 input variables for its decision making. These are:

- speed: the speed of each section
- flow: the flow of each section
- density: the density of each section
- severity: is defined as the speed of section ‘S_c’, which is the section with the lowest average speed during the last time interval of the simulation distance to bottleneck. is defined as the distance of each section from section ‘S_c’. This parameter is defined as 0 for section ‘S_c’ and -1 for all section downstream of ‘S_c’. This is due to the fact that these sections are not affected by the bottleneck and therefore they do not have any speed restrictions. For all sections upstream of ‘S_c’ the “distance to bottleneck” is defined as the distance between the midpoints of ‘S_c’ and each respective section. A typical input to the FLS can be seen in Table 5-2.

Speed	Severity	Flow	Density	Distance to Bottleneck
62.902250	47.211043	6474	27.984806	-1.000000
47.211043	47.211043	5370	41.200201	0.000000
74.001180	47.211043	5874	17.594181	744.698130
98.014791	47.211043	4452	11.544146	3176.457799
95.189536	47.211043	4524	11.970826	2676.471390
94.721520	47.211043	4524	12.119843	2176.447716
94.544298	47.211043	4590	12.215836	1676.423623
73.090995	47.211043	4572	18.018090	1210.391962
78.479575	47.211043	5754	16.137926	372.538510
86.528004	47.211043	6510	18.971357	-1.000000
87.087550	47.211043	6516	18.899906	-1.000000
87.288565	47.211043	6552	18.902816	-1.000000
87.383125	47.211043	6612	19.093569	-1.000000
86.849016	47.211043	6642	19.167799	-1.000000
86.354934	47.211043	6642	19.397275	-1.000000
86.141339	47.211043	6672	19.491962	-1.000000
85.631210	47.211043	6654	19.629595	-1.000000
84.922048	47.211043	6570	19.671721	-1.000000
84.350449	47.211043	6468	19.423599	-1.000000
85.729073	47.211043	6552	19.128576	-1.000000

Each row represents the conditions on one section

Section ‘S_c’ with the lowest average speed during interval T-1

Sections upstream of ‘S_c’. Speeds are restricted at interval T based on the output of the FLS

Sections downstream of ‘S_c’ with no speed restrictions. Distance to bottleneck is defined as -1

Table 5-2: TIA data

The membership functions for the above stated parameters are discussed below.

Distance to bottleneck: This parameter ranges from 0 to 10000 meters and has 4 membership functions as seen in Figure 5-6. These are; nearest, nearer, near & far.

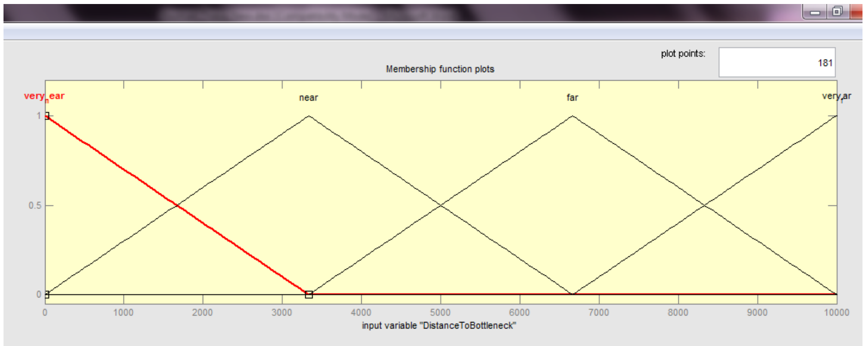


Figure 5-6: Distance to bottleneck

Incident severity: This parameter ranges from 0 to 114 km/h and has 4 membership functions as seen in Figure 5-7. These are low, average, high & very high.

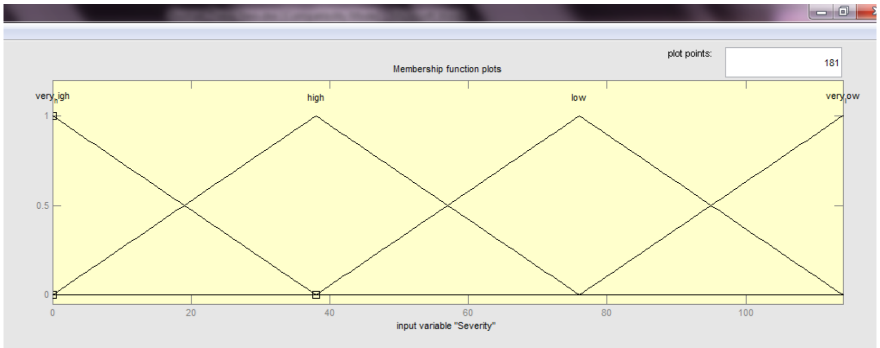


Figure 5-7: Incident severity

Section flow rate: The section flow rate indicates the flow of vehicles within a section. It ranges from 0 to 8400veh/h and has 4 membership functions as seen in figure 5-7. These are free flow, end of free flow, congestion start & congestion.

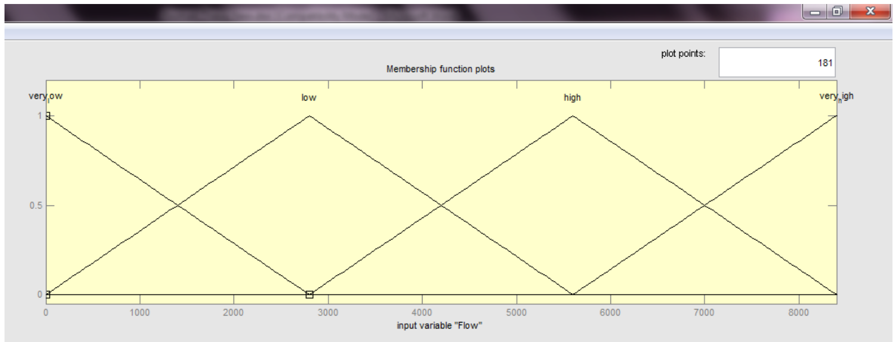


Figure 5-8: Section flow rate

<u>Section average speed</u>: The section average speed is the average speed of the vehicles in that section. It ranges from 0-114km/h and 4 membership functions as seen in Figure 5-9. These are: very slow, slow, average & high.

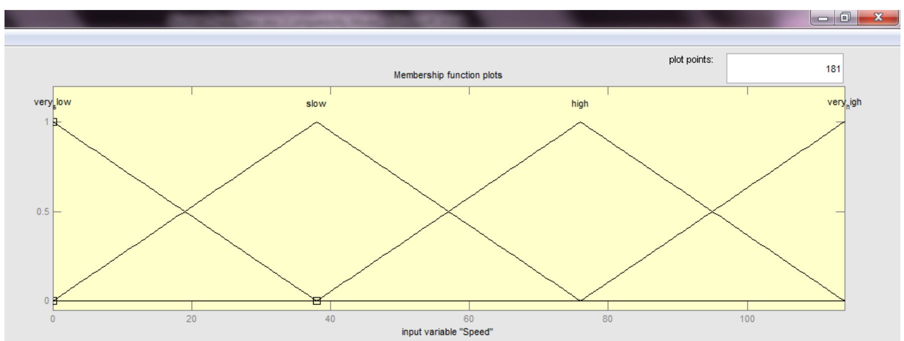


Figure 5-9: Section average speed

<u>Section density</u>: The section density indicates the number of vehicles in a section. It ranges from 0 to 168 veh/km/lane and has 4 membership functions as shown in Figure 5-10.These are; low, average, high & very high.

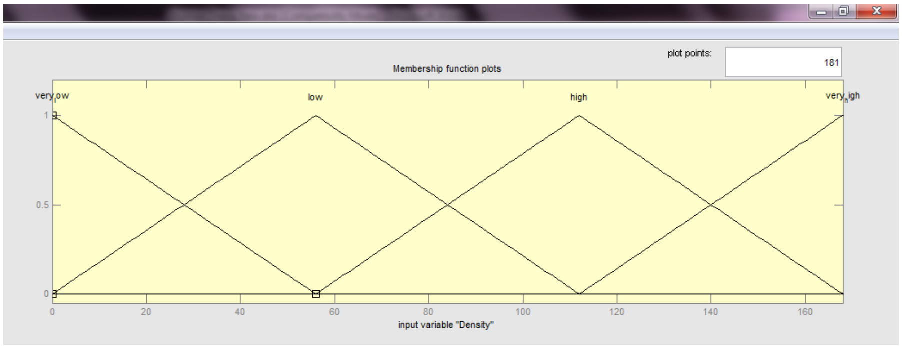


Figure 5-10: Section density

Section Speed Limit: The traffic improvement FIS has 1 output variable i.e. section speed limit: The section speed limit is the imposed speed limit of a section that is calculated by the algorithm based on the input variables. It has 4 membership functions very slow, slow, average & high and it can be seen in Figure 5-11.

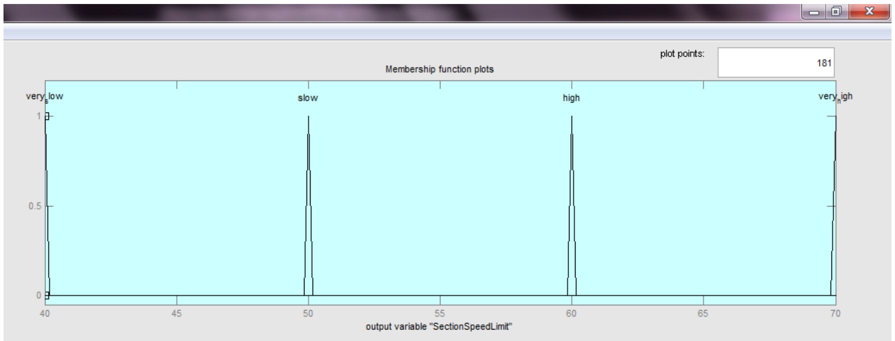


Figure 5-11: Section Speed Limit

For implementing the fuzzy logic within the framework the following function definitions were used. When the function is of the type shown in Figure 5-12, (e.g. very low) the membership function for x, is defined as:

$$\mu(x)=\begin{cases} \min & \text{if } x\le \min \\ \dfrac{x-\max}{\min-\max} & \text{if } x>\min \text{ and } x\le \max \end{cases} \quad \text{-- (3)}$$

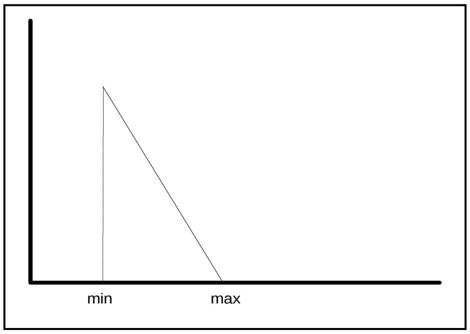


Figure 5-12

When the function is of the type shown in Figure 5-13, (e.g. low, average, etc) the membership function for x, is defined as:

$$\mu(x) = \begin{cases} \dfrac{x - \min}{av - \min} & \text{if } x \geq \min \text{ and } x < av \\ \dfrac{x - \max}{av - \max} & \text{if } x \geq av \text{ and } x \leq \max \end{cases} \quad \text{----- (4)}$$

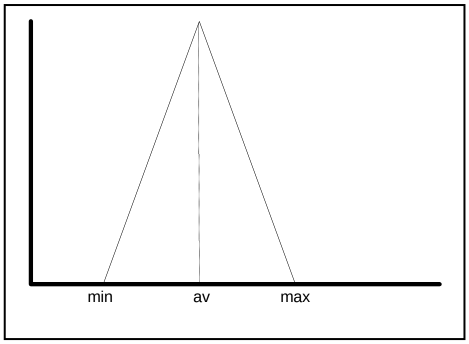


Figure 5-13

When the function is of the type shown in Figure 5-14, (e.g. very high) the membership function for x, is defined as:

$$\mu(x) = \begin{cases} \dfrac{x - \min}{\max - \min} & \text{if } x \geq \min \text{ and } x < \max \\ \max & \text{if } x \geq \max \end{cases} \quad \text{----- (5)}$$

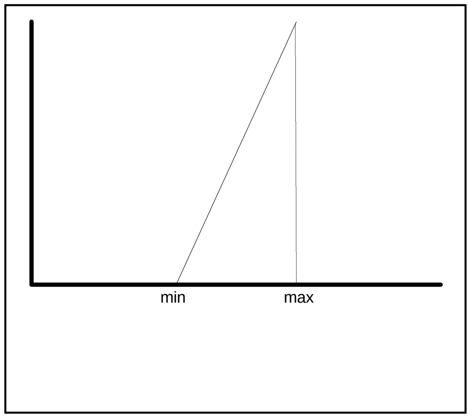


Figure 5-14

The definition of the above is essential for programming the fuzzy logic decision framework. For example consider that the input values as:

- Average speed = 50 kph
- Density = 100 veh/km
- Flow rate = 5000 veh/h
- Incident severity = 60 km/h
- Distance to bottleneck = 5000 m

In order to fuzzify the value we can project it to the fuzzy sets as shown in Figure 5-15.

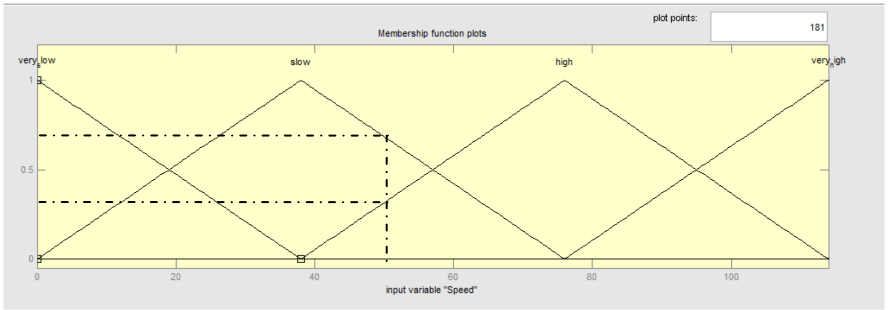


Figure 5-15: Projection of x=50

As it can be seen from the figure above (x) belongs to two sets (slow and high), with different membership values, μ_x (slow) ≈ 0.7, while μ_x (high) ≈ 0.3. However, using the functions presented above the membership values for x can be accurately calculated as follows:

$$\mu_{50}(\text{low}) = \frac{\text{x - max}}{\text{av - max}} = \frac{50-76}{38-76} = \frac{-26}{-38} = 0{,}68,$$

since x=50 , av=38 and max=76 for (low) and $x \geq av, x < max$.

$$\mu_{50}(\text{high}) = \frac{\text{x - min}}{\text{av - min}} = \frac{50-38}{76-38} = \frac{12}{38} = 0{,}31,$$

since x=50 , av=38 and min=0 for (high) and $x \geq min, x < av$.

The membership values for each input parameter in the appropriate fuzzy sets are:

For Average speed

- - $\mu_{50}(\text{low}) = 0.68$
- - $\mu_{50}(\text{high}) = 0.31$

For Incident severity

- - $\mu_{60}(\text{high}) = 0.42$
- - $\mu_{60}(\text{low}) = 0.57$

For Density

- - $\mu_{100}(\text{low}) = 0.21$
- - $\mu_{100}(\text{high}) = 0.78$

For Flow rate

- - $\mu_{5000}(\text{low}) = 0.21$
- - $\mu_{5000}(\text{high}) = 0.78$

For Distance to bottleneck

- - $\mu_{5000}(\text{near}) = 0.5$
- - $\mu_{5000}(\text{far}) = 0.49$

In order to calculate the output of the fuzzy logic system a rule-based knowledge database must be used. This database holds different combinations of linguistic values of the input and output parameters. An example is shown in Table 5-2.

Average Speed	Incident Severity	Density	Flowrate	Distance to Bottleneck	Section Speed Limit
Low (L)	High (H)	Low (L)	Low (L)	Near (N)	Slow (S)
High (H)	Low (L)	High (H)	High (H)	Far (F)	High (H)

Table 5-3: Simulated network statistics

In general the maximum number of rules is equal to the product of the sum of the linguistic values (fuzzy sets), of each parameter; in this case 4 * 4 * 4 * 4 * 4= 1024. However, a fuzzy logic system can weigh up the output with fewer rules. In order to estimate the output of the first association the rules that satisfy the five inputs for each component are:

Average Speed	Incident Severity	Density	Flowrate	Distance to Bottleneck	Section Speed Limit
L	H	L	L	N	S
H	L	H	H	F	H

Table 5-4: Simulated network statistics

The genetic algorithm defines the output for each rule. The behaviour of the fuzzy logic system can change if different outputs are assigned for different cases. In our example we can use the following output assignment Table 5-4 for the rules specified in Table 5-3.

Rule	Average Speed	Incident Severity	Density	Flowrate	Distance to Bottleneck	Section Speed Limit
1	L	H	L	L	N	S
2	H	L	H	H	F	H

Table 5-5: Simulated network statistics

Having defined the rules for the fuzzy logic system, the next step is the defuzzification of the output. For this purpose, the genetic algorithm uses the centre of gravity (COG) defuzzification method by Driankov, H. (1996), which is defined as follows:

$$\frac{\sum_{i=1}^{n} \mu(x_i) \bullet w_i}{\sum_{i=1}^{n} \mu(x_i)}, \qquad \text{----- (6)}$$

where, w_i is the output value of each rule (i.e. if Section Speed Limit is S, w = 50), $\mu(x_i)$ is the truth weight of each rule. The truth of each rule is given from the intersection of the sets that the occasionally input parameters belong to. For Rule 1, and for the membership values, the truth weight is:

$$\mu(x_1) = \mu_{50}(L) \cap \mu_{60}(H) \cap \mu_{100}(L) \cap \mu_{5000}(L) \cap \mu_{5000}(N) \qquad \text{----- (7)}$$

$$= \min(0.68, 0.42, 0.21, 0.21, 0.5) = 0.21$$

Accordingly for the other rules, $\mu(x_2) = 0.31$. For each rule the output values is: $w_1 = 50$, $w_2 = 60$, where n=2;

$$\frac{\sum_{i=1}^{n}\mu(x_i)\bullet w_i}{\sum_{i=1}^{n}\mu(x_i)} = \frac{0.21 * 50 + 0.31 * 60}{0.21 + 0.31} = 55.9 \text{ kph}$$

Based on the input membership functions defined above (5 inputs with 4 membership functions) the number of rules of the developed FIS is 1024. An example of a FIS file that was used as part of the model can be found in Appendix C.

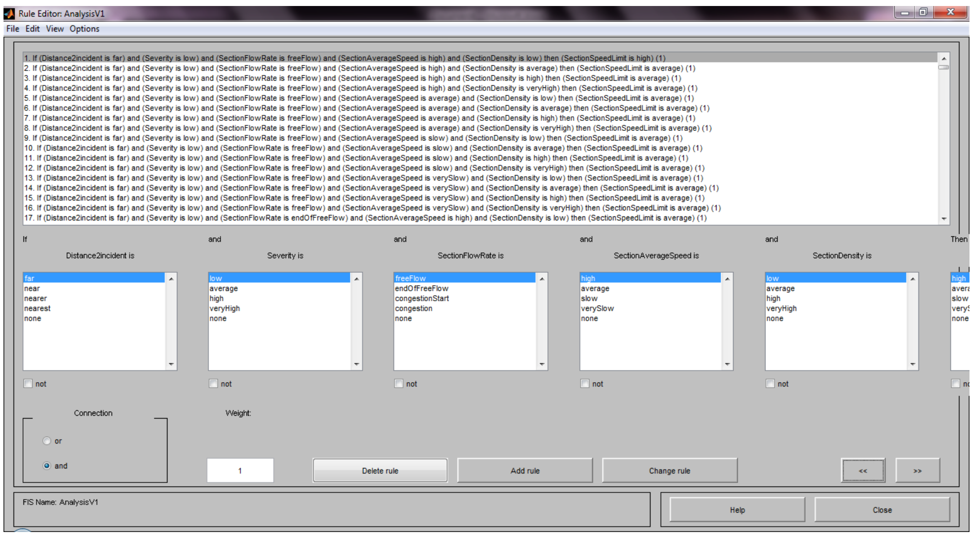


Figure 5-16: FIS rules

In order to optimise the output of each of the 1024 rules of the fuzzy set a genetic algorithm was developed. The details of the generic algorithm method are discussed in the following section.

5.3.3 Genetic algorithm

Conventional AI mostly involves methods now classified as machine learning, characterized by formalism and statistical analysis. This is also known as symbolic AI, logical AI, neat AI and Good Old Fashioned Artificial Intelligence (GOFAI). Genetic Algorithms (GAs) are better than conventional AI. They offer benefits over older AI systems, as they do not break easily with even slight changes in input or noise. Using GAs in performing searches in a large state-space, multimodal state-space, or n-dimensional surface, there are significant benefits than traditional optimisation techniques.

Chipperfield, A.J. (1995) defines GAs as stochastic global search and optimization methods that mimic the metaphor of natural biological evolution. GAs operate on a population of potential solutions applying the principle of survival of the fittest to produce successively better approximations to a solution. At each generation of a GA, a new set of approximations is created by the process of selecting individuals according to their level of fitness in the problem domain and reproducing them using operators borrowed from natural genetics. This process leads to the evolution of populations of individuals that are better suited to their environment than the individuals from which they were created, just as in natural adaptation.

Holland's GA is a method for moving from one population of "chromosomes" (e.g., strings of ones and zeros, or "bits") to a new population by using a kind of "natural selection" together with the genetics inspired operators of crossover, mutation, and inversion. Each chromosome consists of "genes" (e.g., bits), each gene being an instance of a particular "allele" (e.g., 0 or 1). The selection operator chooses those chromosomes in the population that will be allowed to reproduce, and on average the fitter chromosomes produce more offspring than the less fit ones. Crossover exchanges subparts of two chromosomes, roughly mimicking biological recombination between two single chromosomes ("haploid") organisms; mutation randomly changes the allele values of some locations in the chromosome; and inversion reverses the order of a contiguous section of the chromosome, thus rearranging the order in which genes are arrayed.

A typical genetic algorithm (GA) flow chart is shown in Figure 5-17 and the steps taken in applying this to the traffic improvement algorithm is discussed further in this section.

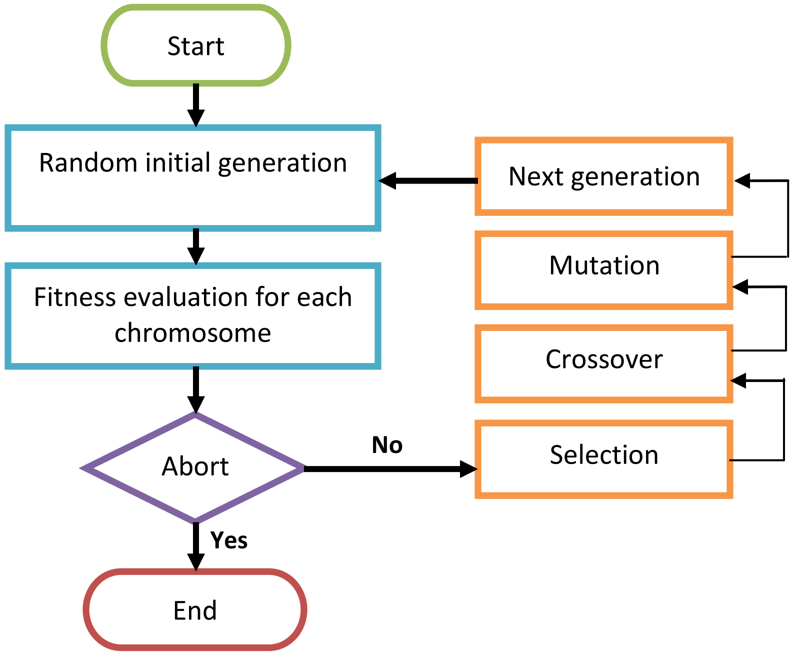


Figure 5-17: Basic Genetic Algorithm flowchart

The following steps discuss various calculation steps performed by the algorithm to achieve improved performance of traffic. The first step was to generate a random population of 50 chromosomes. Each chromosome was comprised of 2048 bits that encoded the outputs of the 1024 rules of the FLS. Since the output of the FLS has four membership functions, two bits were used for representing the output of each rule. The following coding was used.

Bits	Membership Function
00	Very low
01	Low
10	High
11	Very high

Table 5-6: Simulated network statistics

The structure of the Chromosome for the developed GA can be seen in Figure 5-18.

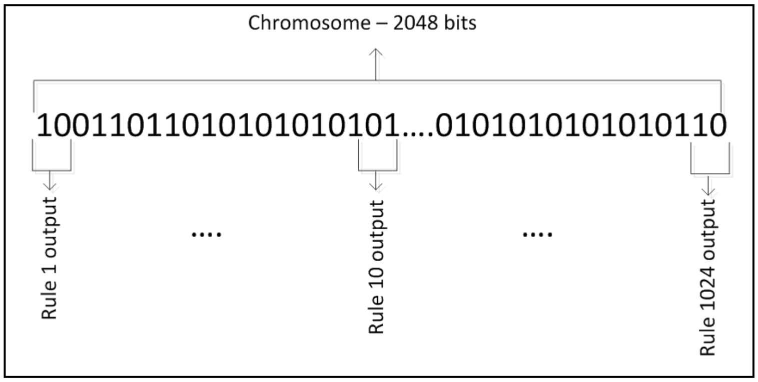


Figure 5-18: Structure of GA chromosome

Using the 50 initial chromosomes, simulations were run in order to evaluate the Total Travel Time that resulted from the application of Variable Speed Limits using the FLS. It can be noted that any (or combination of more than one) simulation parameter could have been selected as the fitness parameter.

The fitness value for each chromosome was evaluated using ranked scaling as discussed in Sadjadi, F. (2004). This approach is suitable when a deterministic technique cannot be applied. This is the case for the traffic improvement algorithm where the dependent variable (speed limit) cannot be directly computed using the input parameters. The equation used can be seen below:

$$f_{ranked} = p - 2\frac{(r-1)(p-1)}{N-1}, \qquad \text{----- (8)}$$

where r is the rank of the individual in the population

p is the "desired selection pressure",

p = *best/median* of the fitness parameter value

It was discovered during the research that the use of elitism resulted in generations where the best and median had the same value. In such cases the mean value was used instead of the median. Following the estimation of the ranked fitness score, the fitness value of each chromosome was calculated using the following equation:

$$f_{score} = \frac{f_{ranked}}{\sum_1^n f_{ranked}} \qquad \text{----- (9)}$$

The derivation of the next generation was based on the fitness score of each chromosome using a combination of roulette selection and elitism techniques. Roulette selection randomly picks chromosomes for the next generation. However, chromosomes with higher fitness scores have a better probability to be selected. Since roulette selection is random in nature, there may be cases where the best chromosomes are not advanced to the next generation. This may result in slow convergence of the algorithm to an optimum value. The use of elitism allows the advancement of the best chromosomes by directly selecting them. One of the drawbacks of elitism is the convergence to a local instead of a global optimum. The performance of the above stated techniques as part of the developed GA is discussed in the next section.

Following the selection of the chromosome, crossover was performed using two crossover points. The cross over probability used was 0.7. The final stage of the GA optimisation involved mutation using 0.001%. This resulted in two (in rare cases three) bits being mutated for each chromosome. The C# code for the implementation of the GA can be found in Appendix G.

5.4 TIA Result Analysis

The GA algorithm was applied under different configurations in order to assess its suitability for improving the Total Travel Time / Total Distance Travelled ratio by imposing variable speed limits on the network. The Aimsun model that was used as part of the evaluation included the simulation of the accident as described in the second control case in section 5.3.2.

Consider the following scenario in which the TIA is running continually at the infrastructure end, the road is divided into sections (500m) and the input parameters (discussed in the previous sections) are fed to the algorithm constantly thus optimising the section speed limit. It is assumed all vehicles in this scenario are equipped with ISA (as discussed in earlier chapters). Figure 5-19 helps to understand the scenario better.

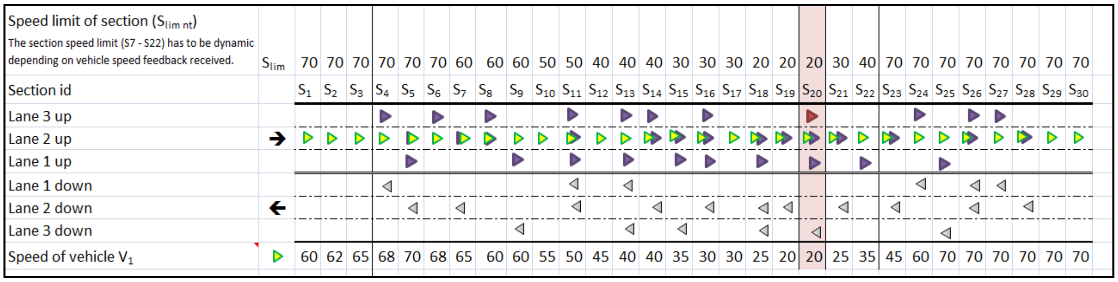


Figure 5-19: Integrated framework / Traffic improvement algorithm scenario

Now let us consider that an incident occurs on a certain section (S_{20}) of the road. These changes the input parameters for every section of the road and the TIA that has been optimising each section of the road has now to rework the speeds of every section. This optimised section speed limit is transmitted to every vehicle via the ISA system. This is a looped process where every vehicle speed is adjusted via the system thus improving the flow and overall traffic. Furthermore, this configuration assigns the intelligent and computational elements of the system to the infrastructure.

The above scenario gives a good illustration of the practical benefit that the framework and TIA would bring. This also addresses and highlights the benefit identified as objectives of this research.

From the simulation setup discussed in section 5.3.2, two GAs were used to optimise the output of the FLS. These are as follows:

A GA that allowed only discrete speed limits (40,50,60 and 70MPH) to be assigned to the sections.

A GA that allowed continuous values as the speed limits (between 40 and 70MPH) to be assigned to the sections.

For the first scenario 68 generations were simulated each taking approximately 3 hours. It was observed that the algorithm converged to a minimum value at 30 generations and therefore this number of generations was used as part of the second scenario.

5.4.1 Analysis -1: Applying Genetic Algorithm

Applying the GAs to the FLS improved the performance of the TIA and resulted to Total Travel Time / Total Distance Travelled ratios considerably lower than the upper limit of 0.0338 identified in section 5.3.2. More specifically for scenario one the ratio achieved by the best chromosome was 0.029286, while for the second scenario the minimum ratio achieved was 0.029856. This demonstrates that the use of discrete and continuous speeds as the FLS output produced comparable results. The GAs optimised the FLS rules and with every generation of a new population the minimum value of 'T' is improved (Figure 5-20 /

Figure 5-21). The 'T' (y-axis) is the travel time variable that equates to travel time by distance travelled.

$$T = \frac{travel\ time}{distance\ travelled} \qquad \text{----- (10)}$$

Whilst the worst case chromosomes of the population appear very erratic, the average and best chromosomes of the population show less variation, and with every new population settle to a smooth waveform.

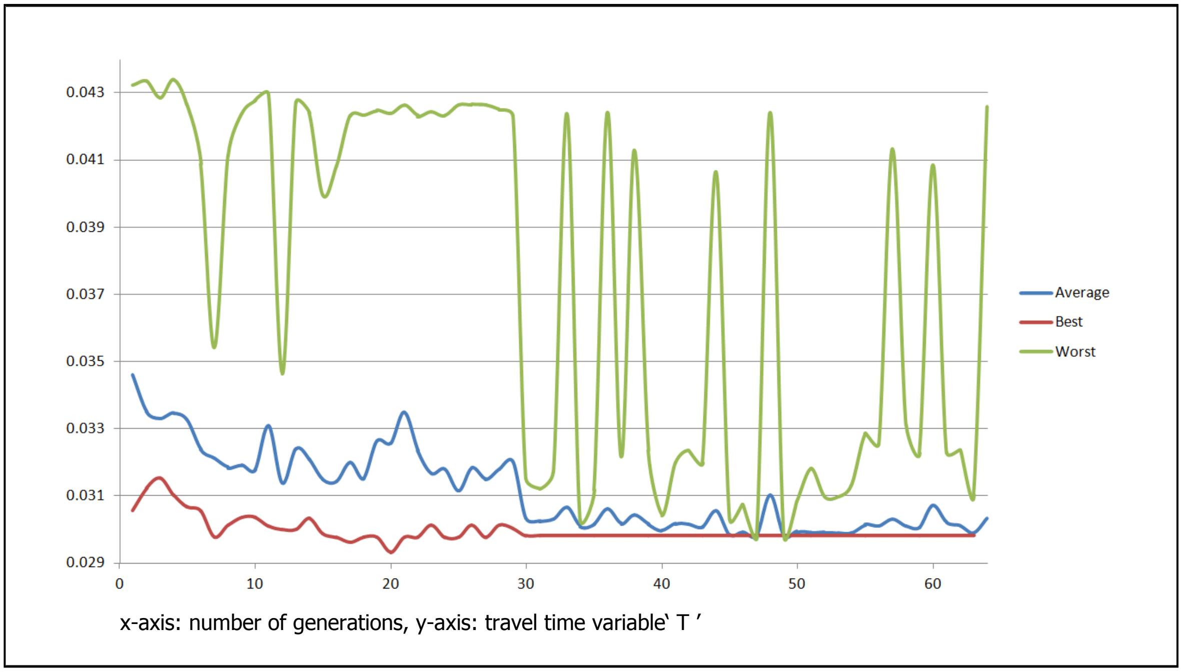
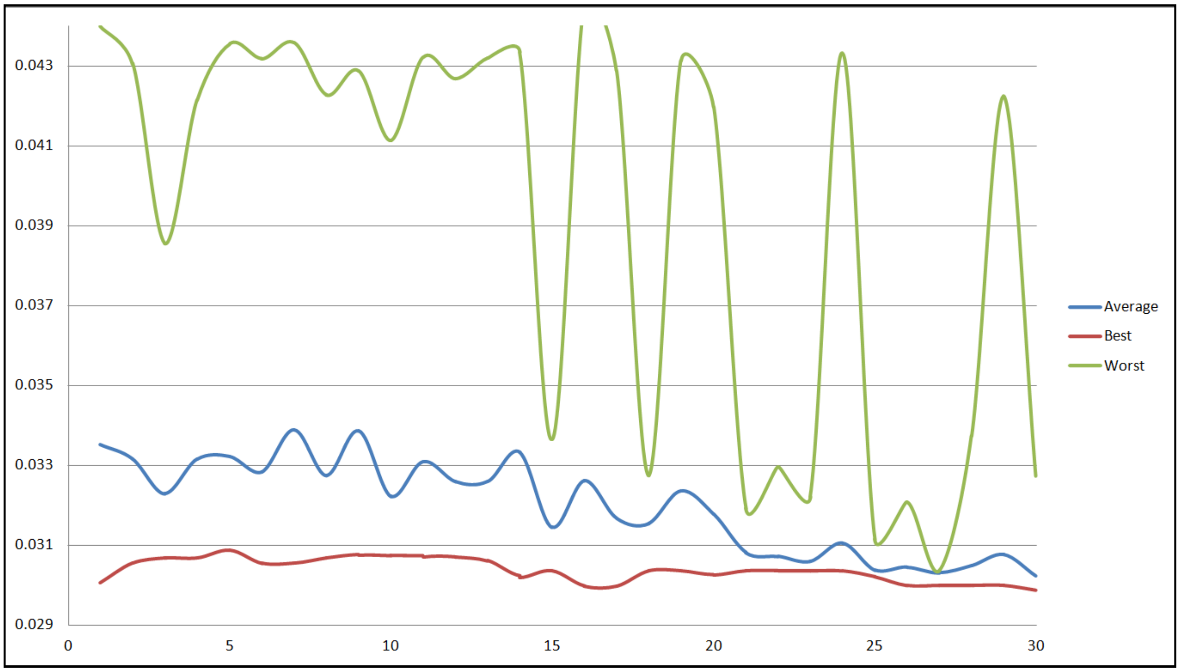


Figure 5-20: Genetic algorithm application – Scenario One



x-axis: number of generations, y-axis: travel time variable' T '

Figure 5-21: Genetic algorithm application – Scenario Two

The graphs in Figure 5-20 indicate the continuous (40 – 60 kmph) speeds on creation of a new population and with Elitism applied. The graphs in

Figure 5-21 indicate the discrete (40, 50 or 60 kmph) speeds on creation of a new population. Comparing them both it is seen that the speed in scenario 1 (continuous) appears to be better than the speed in scenario 2.

5.4.2 Analysis – 2: Density / Speed / Flow rate

From the simulation data the *density* at time 7:55:00 a.m. can be seen (Table 5-6) at its peak, whilst *speed* is minimum at the same time. Now if at this time we compare the performance of the TIA against that of the base case, it can clearly be seen (Table 5-6) that density, speed and flow rates improve when TIA is used. In fact this improvement is also evident at the average values from the entire simulation (Table 5-6).

	Without TIA	**With TIA**	**Units**
At 7:55:00			
Speed	22.48	22.67	km/h
Density	65.43	62.06	veh/km
Flow	7248	7200	veh/h
Average (07:00:00 - 09:00:00)			
Speed	42.87	45.4	km/h
Density	43.64	39.38	veh/km
Flow	5931.5	6092.5	veh/h

Table 5-7: Density, speed & flow rate

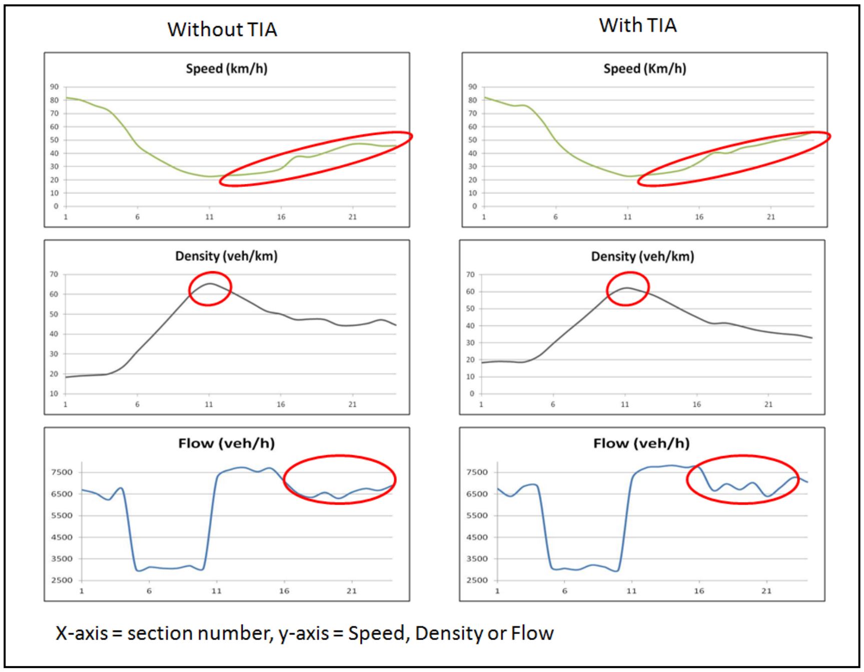


Figure 5-22: Density, speed & flow rate data analysis

5.4.3 Analysis – 3: Improvement of traffic flow

One of the benefits of TIA is illustrated in Figure 5-23. In this figure the section numbers are on the horizontal axis and flow rate (veh/h) is on the vertical axis. A variation of the average flow rates can be calculated using the difference between flow rate with TIA and flow rate without TIA ($F_{FR} = F_{FR\text{-}TIA} - F_{FR\text{-}NoTIA}$). The average data ($F_{FR}$) are all positive values indicating that the traffic performance has improved overall with the introduction of TIA.

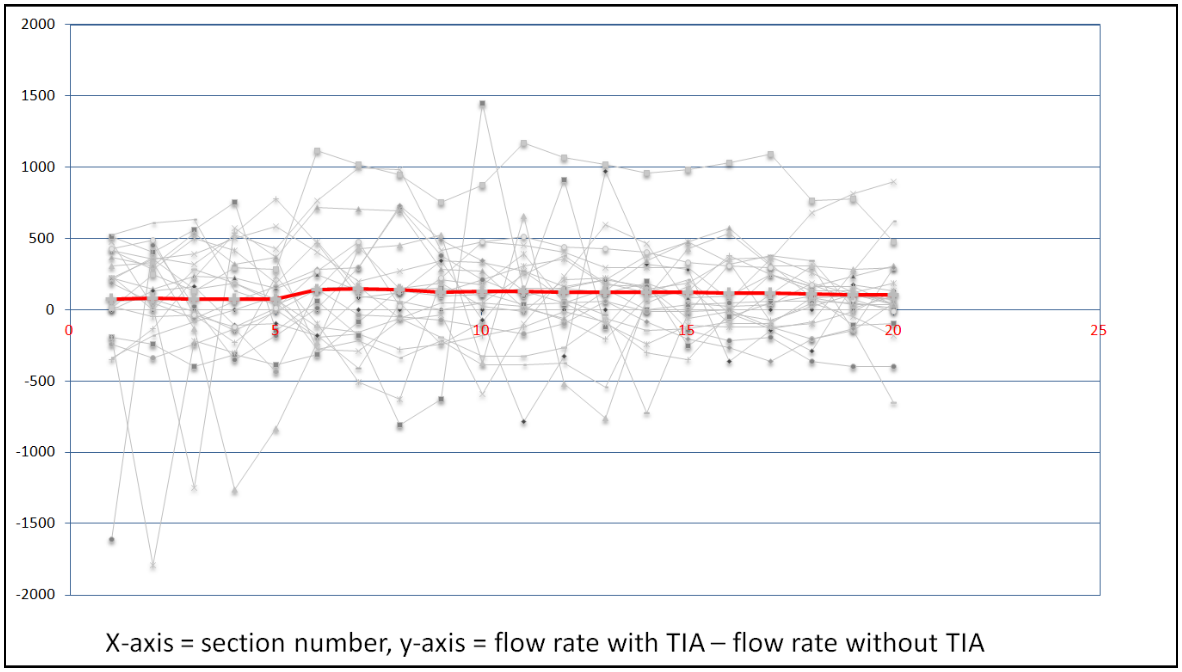
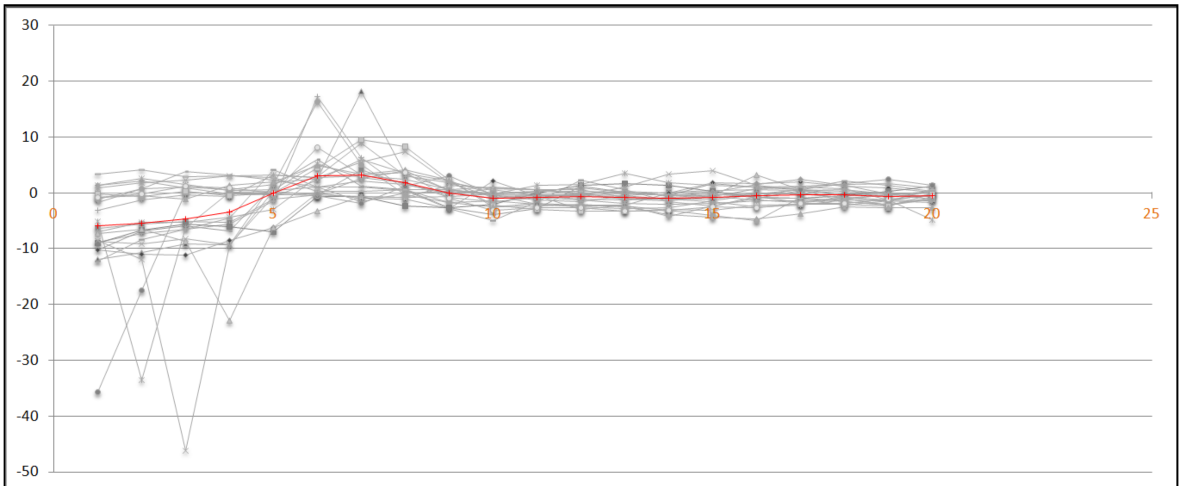


Figure 5-23: Genetic algorithm application – Flow improvement

5.4.4 Analysis – 3: Improvement of average speed

One of the other benefits of TIA is illustrated in Figure 5-24. In this figure the section numbers are on the horizontal axis and speeds (Mph) for each 5-minute interval are on the vertical axis. A variation of the speeds can be calculated using the difference between speed with TIA and flow rate without TIA ($F_S = F_{S\text{-}TIA} - F_{S\text{-}NoTIA}$). An observation from the average speed data (F_S) analysis shows that at the entry and exit points (Figure 5-3) on the road network average speed improves when the TIA is used.



x axis = section number, y axis = average speed with TIA – average speed without TIA

Figure 5-24: Genetic algorithm application – Average speed improvement

5.5 Summary

This chapter discusses the developed TIA, which was evaluated using a traffic simulation tool. The TIA was developed using Fuzzy Inference Logic and Genetic Algorithms and the traffic simulation was done using a microscopic simulation toolkit. Input variables are taken from the traffic simulator and fed to the algorithm. The algorithm then processes the data, and the output, section speed limit is applied to the traffic. This is done repeatedly and traffic performance changes accordingly.

This attempt to improve the traffic scenario is done in a different way as compared to some other attempts discussed in Section 2.6.1. For example, Heydecker, B.G. (2011) uses the speed occupancy relationship in each lane on a motorway to indicate the differences of these two factors from lane to lane. The TIA does not look at a lane level but divides the whole road into sections.

The application of the TIA using real traffic data demonstrated an improvement in the overall performance of the traffic network that was simulated.

The next chapter aims to discuss the influencing factors and model developed that would assist systems engineers to visualise the timeline of launch of such technologies in their respected market.

Chapter 6 : Time-to-market roadmap toolkit

6.1 Introduction

In the previous chapters a model, consisting of 3 main blocks (from an automotive infrastructure perspective), have been discussed. These blocks are:

- vehicle consisting of ITS nodes,
- vehicle-to-base communication channel and
- base infrastructure.

During the development of the conceptual framework, another research gap was identified. This was the *time* a system, or new technology, developed using the framework, would take to come into the end user market. In order to address the identified gap, a novel toolkit was developed. This solution takes into account the various factors influencing a new technology during its development and market introduction phase. This toolkit was developed primarily for automotive technologies, but it can be modified and extended to other areas.

During the course of the research, two ITS technologies (dWIM and ISA) were developed and evaluated. Their functional characteristics were used in the conceptual model of system integration for enforcement ITS. Once such systems are developed it becomes necessary to understand what it would take to bring them into the user market.

The decision making technique that can support the proposed toolkit should ideally be able to use the influence of each criterion at different stages of the project. The techniques that were investigated for the development of the toolkit are reviewed in the following sections.

6.1.1 Weighted Matrix

Weighted matrix is a technique used during decision making that involves different factors. For this method, a matrix is created where each row has an option and each column has a factor and the matrix is completed with a score against each option and weight against each factor. By multiplying the score by weight and summing up for every option, an overall score that takes into account every options various strengths and weaknesses can be obtained.

To get a better understanding of this consider the following example, to find the most preferred transmission in cars in a certain area by a certain group. If the importance level is as shown in Table 6-1.

Relative Importance	Value
Equal importance/quality	1
Somewhat more important/better	3
Definitely more important/better	5
Much more important/better	7
Very much more important/better	9

Table 6-1: Importance level of factors

And the feedback is as below:

- Fully automatic is [much MORE important] than Manual
- Fully automatic is [somewhat MORE important] than Semiautomatic access
- Semi-automatic access is [extremely MORE important] than Manual
- Manual is [extremely LESS important] than Semiautomatic access
- Manual is [much LESS important] than Fully automatic
- Semi-automatic access is [somewhat LESS important] than Fully automatic

	Fully automatic	Manual	Semi-automatic
Fully automatic	1	7	3
Manual	1/7	1	1/9
Semiautomatic	1/3	9	1

Table 6-2: Importance level feedback

Step 1: Rank one transmission type as compared to others

Then the ranking will be as shown in Table 6-3

Step 2: Calculate the overall weighting for each factor by adding each column in the matrix.

	Fully automatic	Manual	Semi-automatic
Fully automatic	1	7	3
Manual	0.14	1	0.11
Semi-automatic	0.33	9	1
TOTAL	1.47	17	4.11

Table 6-3: Feedback ranking

Divide each entry by the total of its column.

	Fully automatic	Manual	Semi-automatic
Fully automatic	0.68	0.4	0.73
Manual	0.1	0.1	0.03
Semi-automatic	0.22	0.5	0.24

Table 6-4: Updated feedback ranking

Step 3: Calculate the averaged final priority vector of each row.

	Fully automatic	Manual	Semi-automatic	Priority Vector
Fully automatic	0.68	0.41	0.73	0.61
Manual	0.10	0.06	0.03	0.06
Semi-automatic	0.22	0.53	0.24	0.33

Table 6-5: Average final priority vector

This weighted score suggests the following:

- Fully automatic is the most popular transmission type represents about 61%
- Nearness to a Fully automatic, Semi-automatic represents about 33% of the decision
- Manual represents about 6% of the decision

6.1.2 Paired Comparison

This technique is used when facing multiple problems or when tasks need to be prioritised. A matrix is created with each task in a row, and the same list as columns. The bottom diagonal of the matrix is blocked out, and there should be one cell for each problem/task pair left. In each cell, the row task is compared with the column task. A score is given based on which is better or preferred. All scores are added for each task and tasks are ranked based on their total as discussed in Dodgson, J S. (2009).

6.1.3 Analytical Hierarchy Process (AHP)

AHP is a multi criteria decision making approach in which factors are arranged in a hierarchical structure. The principles and the philosophy of the theory are summarized giving general background information of the kind of measurement utilized, its properties and applications. AHP is especially suitable for complex decisions, which involve the comparison of decision elements which are difficult to quantify. It is based on the assumption that when faced with a complex decision the natural human reaction is to cluster the decision elements according to their common characteristics. Saaty, T. L. (2008) states that AHP is a theory of measurement through pair wise comparisons and relies on the judgements of experts to derive priority scales. It involves building a hierarchy (ranking) of decision elements and then making comparisons between each possible pair in each cluster (as a matrix). This gives a weighting for each element within a cluster (or level of the hierarchy) and also a consistency ratio (useful for checking the consistency of the data).

6.1.4 Application of Multi Criteria Analysis

The objective of this research is to predict the time to market which is influenced by a number of factors. This meant that the important criteria of AHP which is to specify a number of alternatives cannot be achieved. Hence, a Multi-Criteria Analysis (MCA) tool was used instead of a single analysis tool like AHP.

An advantage of using MCA is that users do not have to agree on the relative importance of the criteria, or the rankings of the alternatives. A user enters their independent judgements and makes a distinct, identifiable contribution to a jointly reached conclusion.

There are in general seven influencing factors that dictate the period required for a new technology to reach the market. In order to understand their influence an extensive research was conducted. A model was developed that could assist systems engineers to get an improvised prediction of this time to market.

The input to the MCA tool was obtained from a separately developed questionnaire. The results obtained from this questionnaire were fed into a MCA spreadsheet tool, which gave an indicative time-to-market for the technology based on the seven factors. These questionnaires were completed by experts from the automotive (two) and electronics industries. Different OEMs have adopted different techniques and processes which they follow when adopting and introducing their products.

The functionality of the developed toolkit was evaluated using data from existing technologies. This was to ensure the validity of the results and the robustness of the model. The model was then applied to various other existing automotive technologies (both old and current).

Automotive technologies are hugely influenced by various factors that can be categorised into seven main influencing factors which are:

- Customer Demand (Customer requirement)
- Competitive pressure
- Product Differentiation

- Technology (Product engineering)
- Market dependencies and
- Business case
- Legal Challenges (Legal / legislative impact)

With the view of the factors mentioned above, it helps to investigate their impact on the product launch timing.

6.2 Questionnaire

The questionnaire discussed later in this chapter acts a supporting input component for the toolkit. For the development of this toolkit, the questionnaire is not used as a statistical tool but rather complements and supports other components within the framework. Unlike the typical applications of questionnaires where a high number of responses is required, this is not the case here.

The design of this questionnaire is specific to the automotive industry. It was essential that the candidates completing this questionnaire are qualified and well experienced. Hence, selective sampling approach was applied to ensure valid responses. The potential candidates who completed this questionnaire are high eminent profiles (13), active within the British car industry. The roles of these participants varied from technical specialists (3), senior engineers (5), and project engineers (2) to head of departments (4) from some of the most popular British car manufacturers (2) and a supplier (1).

The questionnaire was developed as a web application, consisting of a multiple choice form (Figure 6-2). This was followed by a brief description of the various criteria that are applicable, followed by instructions on how the questionnaire should be completed. The participants were requested to select one of the vehicle technologies. Then based on that technology the participants were expected to provide their feedback by selecting the best option from their point of view. All the responses were sent to an email address (Figure 6-1) when the submit button was clicked.

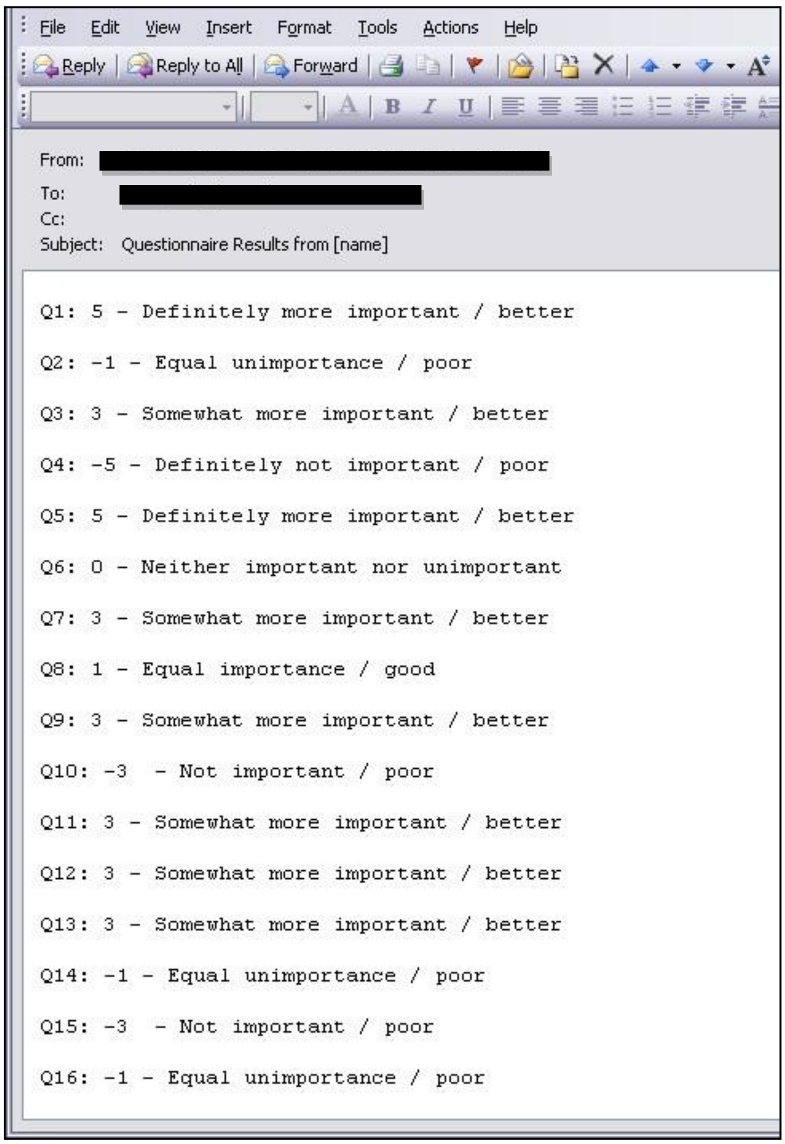
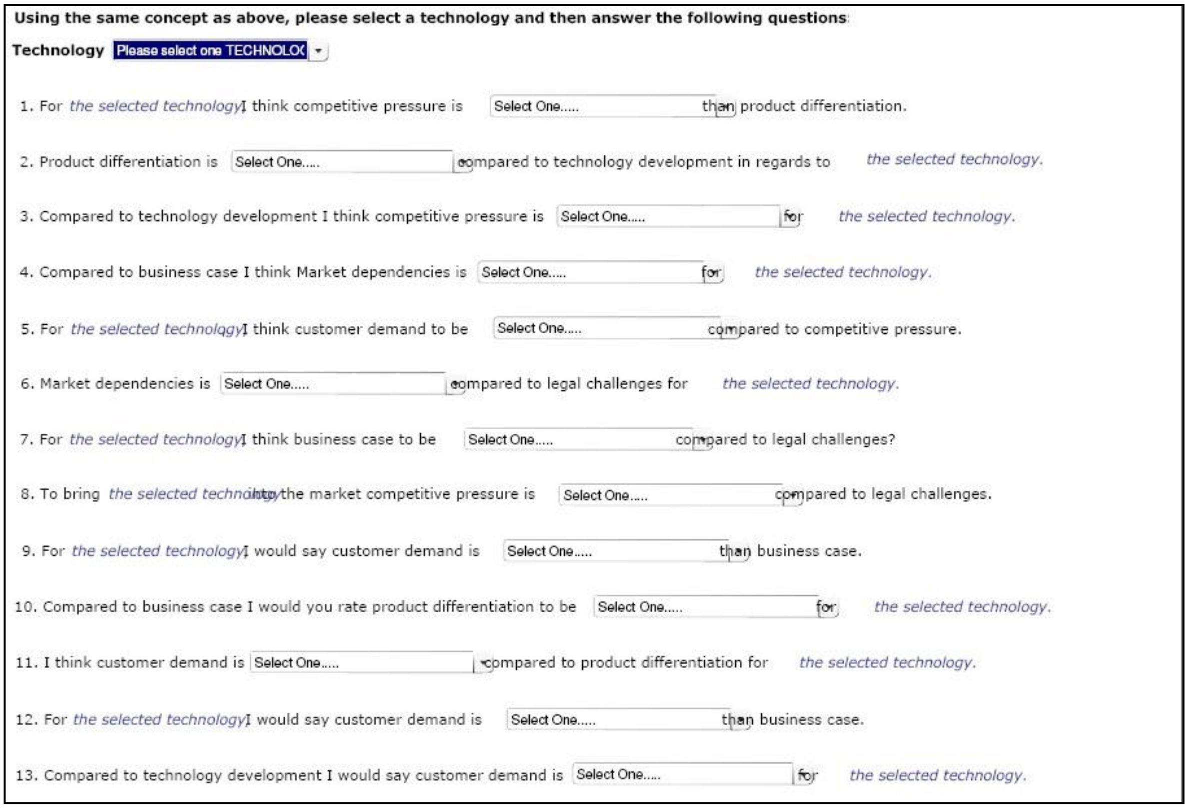


Figure 6-1: Results email response screenshot

6.2.1 Questionnaire Specification

The questionnaire had 21 questions and each question had 19 options from which the participant was expected to select one answer. Upon answering the 21 questions, the participant was expected to complete a brief personal detail form (of which the name is not stored to maintain confidentiality) to identify the response. Only form elements such as the role and company name were kept on file.

In order to evaluate the questionnaire the relative importance of the different criteria, paired comparison analysis (Section 6.1.2) was used in conjunction with analytic hierarchy process (Section 6.1.3). The multiple choice answers are a range from -9 to +9. Selecting a negative number indicates lower priority and selecting a positive number indicates a higher priority.



Using the same concept as above, please select a technology and then answer the following questions

Technology Please select one TECHNOLOG

1. For *the selected technology* I think competitive pressure is Select One..... than product differentiation.

2. Product differentiation is Select One..... compared to technology development in regards to *the selected technology.*

3. Compared to technology development I think competitive pressure is Select One..... for *the selected technology.*

4. Compared to business case I think Market dependencies is Select One..... for *the selected technology.*

5. For *the selected technology* I think customer demand to be Select One..... compared to competitive pressure.

6. Market dependencies is Select One..... compared to legal challenges for *the selected technology.*

7. For *the selected technology* I think business case to be Select One..... compared to legal challenges?

8. To bring *the selected technology* into the market competitive pressure is Select One..... compared to legal challenges.

9. For *the selected technology* I would say customer demand is Select One..... than business case.

10. Compared to business case I would you rate product differentiation to be Select One..... for *the selected technology.*

11. I think customer demand is Select One..... compared to product differentiation for *the selected technology.*

12. For *the selected technology* I would say customer demand is Select One..... than business case.

13. Compared to technology development I would say customer demand is Select One..... for *the selected technology.*

Figure 6-2: Questionnaire sample screenshot

Paired Comparison Analysis helps to work out the importance of a number of options relative to each other and also helps determine the criteria preferences. Once this has been worked out, AHP along with paired comparison is used to determine the relative weights of various criteria. These weights are then applied to every stage within the project, thus giving an overall calculated time affected by these criterions. On completion, the results from the questionnaire indicate the influence of each criterion every stage of the project. This evaluation has shown how some criterion has influenced a project stage causing the launch to deviate from its timing.

All responses were then imported in an excel sheet (see Figure 6-3) and used to derive the graph. In order to do this the following steps are followed:

Que	Score	Conv
Q1:	-9	0.11
Q2:	0	1.00
Q3:	3	3.00
Q4:	7	7.00
Q5:	-9	0.11
Q6:	-9	0.11
Q7:	-9	0.11
Q8:	3	3.00
Q9:	9	9.00
Q10:	1	1.10
Q11:	7	7.00
Q12:	-7	0.14
Q13:	3	3.00
Q14:	1	1.10
Q15:	0	1.00
Q16:	5	5.00
Q17:	0	1.00
Q18:	-3	0.33
Q19:	7	7.00
Q20:	5	5.00
Q21:	-7	0.14

	Customer Demand	Competitive Pressure	Product Differentiation	Technology	Market Dependencies	Business Case	Legal Challenges
Customer Demand	1.00	0.11	7.00	0.33	0.33	9.00	1.00
Competitive Pressure	9.00	1.00	0.11	0.33	5.00	5.00	3.00
Product Differentiation	0.14	9.00	1.00	1.00	7.00	0.91	1.10
Technology	3.00	3.00	1.00	1.0	7.00	1.00	0.14
Market Dependencies	3.00	0.20	0.14	0.1	1.00	0.14	0.11
Business Case	0.11	0.20	1.10	1.00	7.00	1.00	0.11
Legal Challenges	1.00	0.33	0.91	7.0	9.00	9.00	1.00
Total	17.25	13.84	11.26	1[illegible].81	36.33	26.05	6.47

	Customer Demand	Competitive Pressure	Product Differentiation	Technology	Market Dependencies	Business Case	Legal Challenges	Priority Vector	
Customer Demand	0.06	0.01	0.62	0.03	0.01	0.35	0.15	0.18	←PV_{CD}
Competitive Pressure	0.52	0.07	0.01	0.03	0.14	0.19	0.46	0.24	←PV_{CP}
Product Differentiation	0.01	0.65	0.09	0.09	0.19	0.03	0.17	0.25	←PV_{PD}
Technology	0.17	0.22	0.09	0.09	0.19	0.04	0.02	0.21	←PV_{T}
Market Dependencies	0.17	0.01	0.01	0.01	0.03	0.01	0.02	0.09	←PV_{MD}
Business Case	0.01	0.01	0.10	0.09	0.19	0.04	0.02	0.23	←PV_{BC}
Legal Challenges	0.06	0.02	0.08	0.65	0.25	0.35	0.15	1.56	←PV_{LC}

	Technology Kick-Off	Technology Strategy	Concept Readiness	Application Readiness	Implementation Readiness	
Normal Time (NT)	1	3	9	15	9	
Customer Demand	0.18	0.53	1.58	2.63	1.58	6.49
Competitive Pressure	0.24	0.71	2.14	3.57	2.14	8.81
Product Differentiation	0.25	0.74	2.23	3.71	2.23	9.16
Technology	0.21	0.62	1.86	3.09	1.86	7.63
Market Dependencies	0.09	0.26	0.79	1.32	0.79	3.26
Business Case	0.23	0.69	2.07	3.44	2.07	8.50
Legal Challenges	1.56	4.67	14.02	23.37	14.02	57.65
Actual	2.74	8.23	24.69	41.15	24.69	8.46

Figure 6-3: Results analysis screenshot

Responses are first converted into their respective weight of factors (**W_F**) with negative numbers being converted into fraction equivalents. Example of this is shown in Table 6-6. These weights are then populated in their respected fields (cells) in the spreadsheet.

0	1/1	1.00
1	1.1/1	1.10
2	2/1	2.00
3	3/1	3.00
4	4/1	4.00
5	5/1	5.00
-1	1/1.1	0.91
-2	1/2	0.50
-3	1/3	0.33
-4	1/4	0.25
-5	1/5	0.20

Table 6-6: Converting ratings into weight of factors

The next step is to calculate the ratings, and this is done by adding each column ratings (weights of factor). Total (which is the total weight of each factor).

$$\mathbf{W_{CD}} = \sum_{i=1}^{7} \mathrm{WCDi} \qquad \text{----- (11)}$$

Note: The above formula calculates the weight factor for each criteria, for example Customer Demand (CD). The same process is followed for the remaining factors such as Competitive Pressure (CP), Product Differentiation (PD), Technology (T), Market Dependencies (MD), Business Case (BC) and Legal Challenges (LC).

By dividing each entry by the total of its column (1/17.25, 0.1/13.84, 7/11.26, etc.) thus, creating another matrix (second table below the first one).

$$\mathbf{RW_{CDi}} = \sum_{i=1}^{7} \frac{\text{WCD}i}{\text{WCD}} \qquad \text{----- (12)}$$

Note: The above formula calculates the Weight factor (second table) which is Customer Demand (CD). The same is calculated for remaining factors such as Competitive Pressure (CP), Product Differentiation (PD), Technology (T), Market Dependencies (MD), Business Case (BC) and Legal Challenges (LC).

This was followed by calculating the overall weighting of each criterion and standardising the weights. Because the weights are subjective, inconsistencies are often seen. In order to smooth these, the average of each row is calculated (priority vector in the second table). This is the final weight for each criterion.

$$\mathbf{PV_{CD}} = \frac{\text{WCD1} + \text{WCP1} + \text{WPD1} + \text{WT1} + \text{WMD1} + \text{WBC1} + \text{WLC1}}{7} \qquad \text{----- (13)}$$

$$\mathbf{PV_{CP}} = \frac{\text{WCD2} + \text{WCP2} + \text{WPD2} + \text{WT2} + \text{WMD2} + \text{WBC2} + \text{WLC2}}{7} \qquad \text{----- (14)}$$

$$\mathbf{PV_{PD}} = \frac{\text{WCD3} + \text{WCP3} + \text{WPD3} + \text{WT3} + \text{WMD3} + \text{WBC3} + \text{WLC3}}{7} \qquad \text{----- (15)}$$

$$\mathbf{PV_{T}} = \frac{\text{WCD4} + \text{WCP4} + \text{WPD4} + \text{WT4} + \text{WMD4} + \text{WBC4} + \text{WLC4}}{7} \qquad \text{----- (16)}$$

$$\mathbf{PV_{MD}} = \frac{\text{WCD5} + \text{WCP5} + \text{WPD5} + \text{WT5} + \text{WMD5} + \text{WBC5} + \text{WLC5}}{7} \qquad \text{----- (17)}$$

$$\mathbf{PV_{BC}} = \frac{\text{WCD6} + \text{WCP6} + \text{WPD6} + \text{WT6} + \text{WMD6} + \text{WBC6} + \text{WLC6}}{7} \qquad \text{----- (18)}$$

$$\mathbf{PV_{LC}} = \frac{WCD7 + WCP7 + WPD7 + WT7 + WMD7 + WBC7 + WLC7}{7} \quad \text{----- (19)}$$

These priority vectors are then multiplied with time in weeks (normal time, NT) each stage of the project (5 stages in this case), which gives a clear understanding of how each stage of the project was affected by these criteria. Under ideal conditions, each stage would take the specified time to complete, but due to the effect of these criteria every stage time varies. Each stage of the project multiplied by its priority vector is then plotted to indicate a graphical analysis to show the variation from the ideal conditions (Row F32 – J32).

$\mathbf{TK} = PV_{CD}*1 + PV_{CP}*1 + PV_{PD}*1 + PV_{T}*1 + PV_{MD}*1 + PV_{BC}*1 + PV_{LC}*1$

$\mathbf{TS} = PV_{CD}*3 + PV_{CP}*3 + PV_{PD}*3 + PV_{T}*3 + PV_{MD}*3 + PV_{BC}*3 + PV_{LC}*3$

$\mathbf{CR} = PV_{CD}*9 + PV_{CP}*9 + PV_{PD}*9 + PV_{T}*9 + PV_{MD}*9 + PV_{BC}*9 + PV_{LC}*9$

$\mathbf{AR} = PV_{CD}*15 + PV_{CP}*15 + PV_{PD}*15 + PV_{T}*15 + PV_{MD}*15 + PV_{BC}*15 + PV_{LC}*15$

$\mathbf{IR} = PV_{CD}*9 + PV_{CP}*9 + PV_{PD}*9 + PV_{T}*9 + PV_{MD}*9 + PV_{BC}*9 + PV_{LC}*9$

The final time to market (TM) in years is then the sum of all affected criteria (in weeks).

$$\mathbf{TM} = = \frac{TK + TS + CR + AR + IR}{12} \quad \text{----- (20)}$$

The output and obtained resultant of the questionnaire is the time that a technology would take to enter the market after being influenced by the various factors at different stages of the project. The level of effect of these factors is specified by participants (market experts).

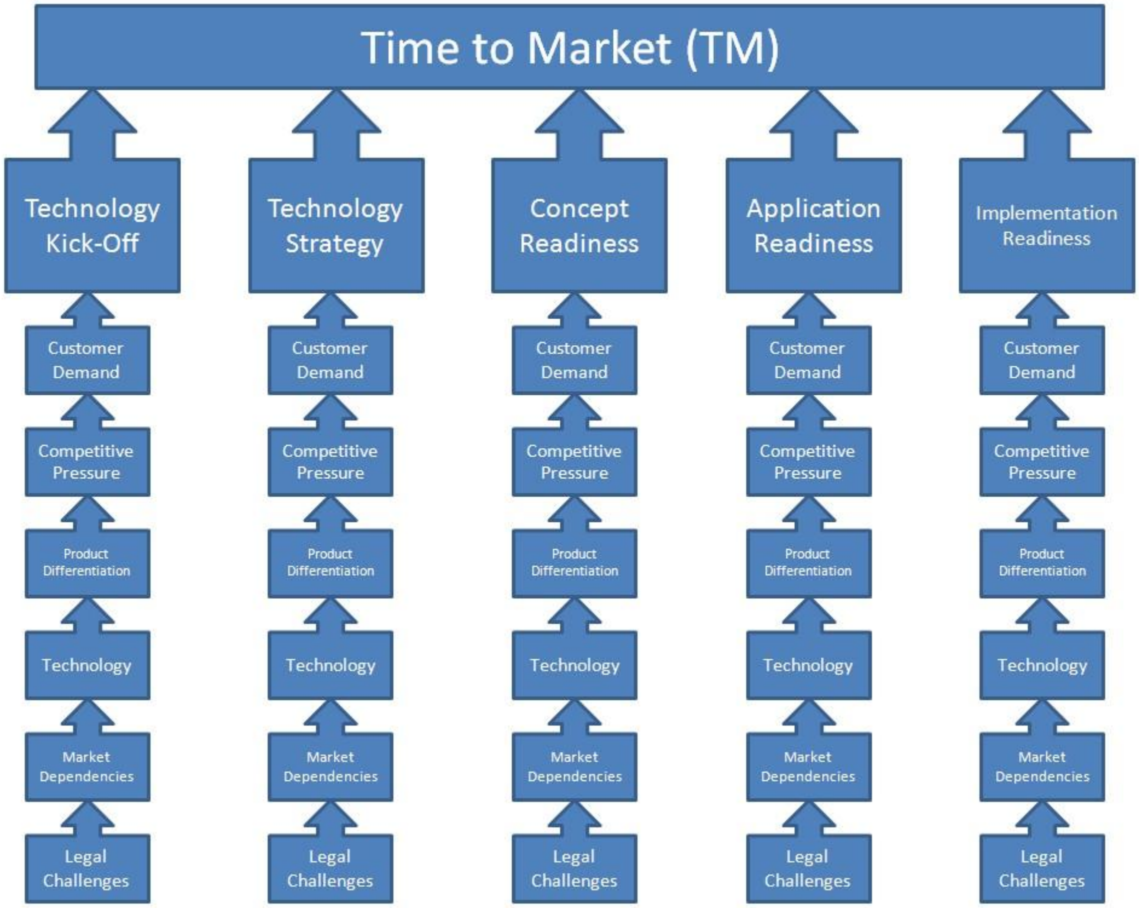


Figure 6-4: Time to market sample hierarchy

6.2.1.a <u>Calculation of the "Normal" curve</u>

For analysis of the results discussed in the next few sections, (6.3.1– 6.3.4) two types of data are used. The first one was the normal data (normal data is the time taken at each stage of the project without any influence from any factors), and the other is derived from the questionnaire results, hence labelled as candidates 1, 2, 3, etc.

The normal data (time) is derived from the point in time when the technology was first conceptualised / invented / discovered as a system to the time the concept was released in the market for the first time. For example as stated in the Bluetooth SIG, (2010), Bluetooth was first introduced as a concept in 1994 by Ericsson. This technology later matured and entered the automotive market in 2001.

Each technology discussed and data captured by the questionnaire show similar patterns ("normal" curve). This curve is seen only for technologies that are already in the market. Hence it can be used to confirm the deviation between the time it actually came into the market to the time it was predicted to come into the market. In order to get an accurate result, the deviation between these two curves should be as small as possible.

6.3 Result Analysis

The results and analysis of the questionnaire are presented in this chapter under different sections based on the technology.

6.3.1 Restraints Technology

Airbags technology is one of the leading vehicle safety systems that are seen widely in cars as standard. An American inventor, John W. Hetrick, designed the original safety cushion for automotive use in 1952. His patent lasted only 17 years - long before mainstream automotive usage. Breed Corporation then marketed this innovation first in 1967 to Chrysler. If the generic product development model along with the criteria discussed in the literature review was applied to this restraints system in 1967, it would take 9 – 10 years before it came into the market (ref: questionnaire results). This time was evaluated using feedback from the questionnaire. A trace of different candidate's feedback can be seen as a graphical view (Figure 6-5).

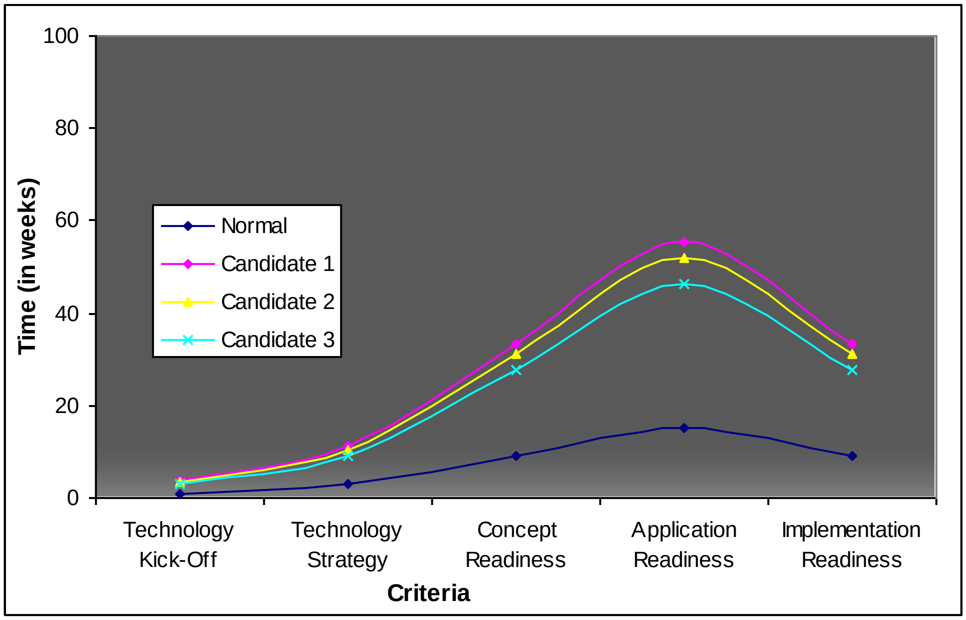


Figure 6-5: Restraints Electronics Technology Results Analysis

The deviation from the time it took the first restraints system to come into the market from the time experts think it would take has deviation of around 3½ years. This indicates how a safety critical technology in recent times can be influenced at various project stages and invariably cause a longer time to introduction into the market.

Restraint technologies, which consist of, systems such as airbag technology, seatbelts, etc. are safety critical technologies. Such systems are thoroughly examined at every stage of the project and go through stringent release processes. This leads to the increase in time they can enter the market.

6.3.2 Bluetooth Technology

The popular short range communication technology known as Bluetooth was first introduced by Ericsson as a concept in 1994. Bluetooth was later formed as a special interest group (SIG) with its first specification released in 1998. However, it was not until 2001 when the first car application of Bluetooth was seen.

A trace of different candidate's feedback can be seen as a graphical view (Figure 6-6). Bluetooth is the latest short range technology. In the era that Bluetooth was conceptualised, the industries were quite experienced in managing various factors that affect the technology launch. Hence, applying the different factors to this technology would give much more accurate result thus reducing the deviation.

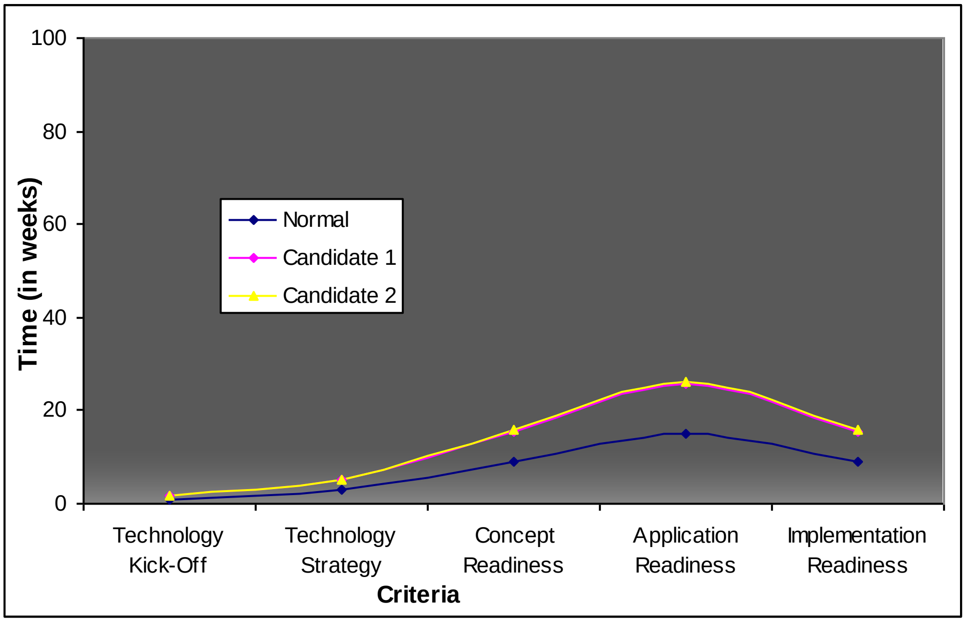


Figure 6-6: Bluetooth Technology Results Analysis

6.3.3 Pedestrian Safety Technology

Jaguar began their research in the area of pedestrian safety (deployable bonnet) in 1999. They were the first car OEM to introduce this system in their car in 2005. This equates to around 7 years before the product hit the market from concept stage. Using the questionnaire as a tool and considering all criteria and expert opinions, the average time to market equates to 7.7 years. The comparable deviation between the actual time to market to what the experts have thought to be had averaged to 7 months. A graphical representation of the analysis can be seen in Figure 6-7.

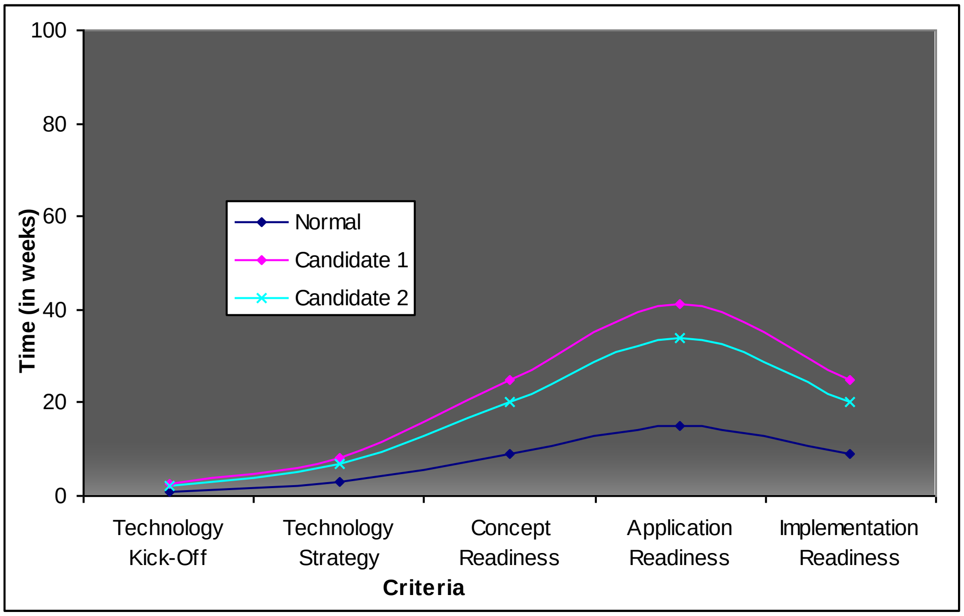


Figure 6-7: Pedestrian Safety Technology Results Analysis

6.3.4 Intelligent Speed Adaptation Technology

Intelligent speed adaptation research peaked and trials began in 2005. Carsten, (2001), have conducted a research led by the University of Leeds and MIRA predicts that mandatory ISA will be seen in cars around 2013. A period of around 9 years before ISA will come into the market. Using the questionnaire method, experts were asked to indicate their opinion of how each criterion would affect ISAs project based on various project stages. From Figure 6-8, the time to market for ISA can be derived around 10 years.

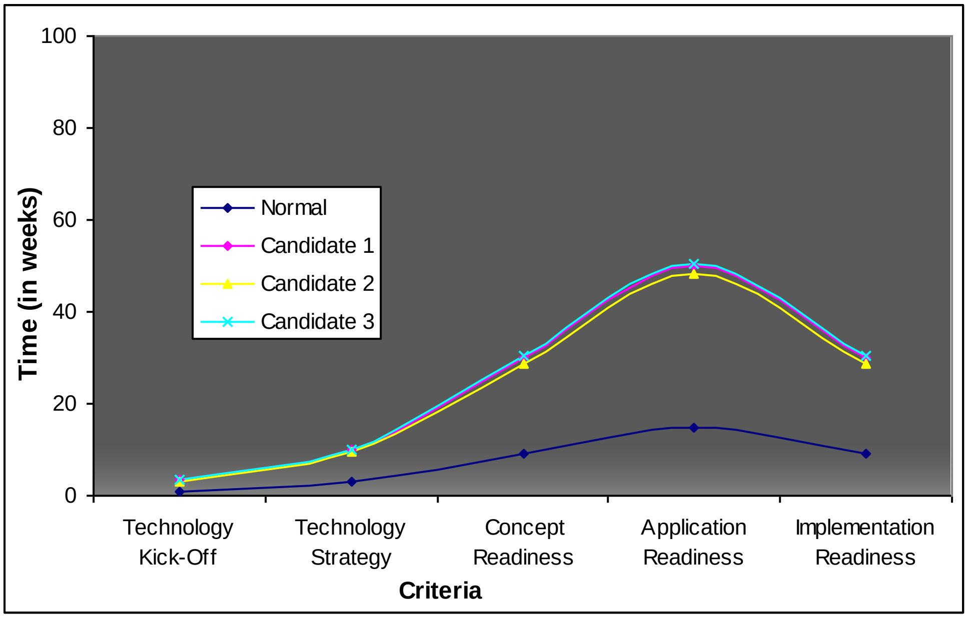


Figure 6-8: Intelligent Speed Adaptation Results Analysis

6.4 Summary

The above analysis and observations indicate a trend of accuracy as time evolved. For all four technologies that were used to evaluate the toolkit, although some deviation between market experts opinion from the "Normal" curve does exist, the deviation itself is minimum indicating the consistency of results. This implies that the technique adopted, and the design of the toolkit gives the expected desired output with some deviation. Initially when the toolkit was used for old technologies such as restraints technology, the deviation from the toolkit's output analysis and actual time to market was as high as 3½ years. By using the toolkit on more recent technologies such as Bluetooth and Pedestrian safety technologies, the deviation gap was narrower, ranging from 1.3 years to 7 months. The "normal" curve is the actual time the technology takes to enter the market from concept stage, and this is accurate to existing technologies as we know the time the technology was at the concept level to the time it took to enter the market. On the other hand, industry experts, when launching a new technology, apply various methods to the project covering every aspect affecting the technology to ensure a successful launch and life of the technology. The people involved in technology development and research use latest methods and follow well structured processes before bringing a new technology into the market. From the resulting analysis of various technologies, it is seen that as processes mature, time to market for new technologies improve. In 1960s, stringent processes were not widely adopted during technology releases, but since OEMs have started adopting project management processes the ability to predict time to market has improved. Furthermore, the results seen in the graphical form indicate a greater level of consistency in the actual data and expert's opinion.

The results achieved from the toolkit indicate consistency of data from the input channels (market experts) on comparing it to past and current technologies and thus, validates the toolkit design.

This chapter has discussed a novel toolkit that uses a multicriteria analysis model supported by industry's expert feedback (in the form of a questionnaire) to predict the time required for a new technology to enter the market. This model acts as a supporting tool for the integrated framework that was developed as part of this research.

Chapter 7 : Conclusions and Further Work

7.1 Introduction

The development of the ITS and related architecture must consider the role and interaction with backend delivery platforms (infrastructure). This can be achieved by applying Service Oriented Architecture (SOA) concept. Rather than taking the approach of producing unique architectures for each deployment, Jesty, P.H. (2011) identifies that it would be much more efficient to have framework architecture, from which independent ITS architectures can be developed.

This thesis has dealt with the issue relating to the limited application of an integrated framework for the ITS and the infrastructure. Applying the proposed architecture and employing a novel algorithm to show the benefits of the integrated approach has helped to tackle the traffic performance issue. Section 7.2 discusses the proposed architecture and its application to a traffic scenario. Section 7.2 also discusses a time-to-market toolkit that is developed and presented. Section 7.3 discusses some other contributions such as system and concept designs to validate the framework. Section 7.4 discusses the future research directions and opportunities that have arisen during the development of this research and finally section 7.5 gives the closing remarks.

7.2 Main contribution

Every component (vehicle applications, vehicle to vehicle communication and infrastructure tools) within ITS adheres or tries to, by using some form of standard protocols, and each component achieves this within its own limits. As a result, they end up operating independently. Furthermore, the integration of the infrastructure with such ITS system is limited (ETC, ANPR, etc.). The various reviews identified this and a number of other gaps that the research aimed to address. These gaps are listed below:

- ITS bring many benefits in the form of various intelligent applications. With the increase in intelligence, in vehicle applications computing power also increases. This means that vehicles now demand more computing power and will eventually limit themselves,
- Current traffic management techniques use methods such as variable speed limits to maintain a constant traffic flow or improve traffic in an event of an incident. However, using such methods will increase excessively stop-and-go occurrences,
- New concepts in the automotive and technology industry are becoming increasingly visible. However, both developers and end-users lack the ability to determine the time a new concept would take to enter the end-user market. This demands a time-to-market application that addresses this issue that is influenced by various factors discussed in section 6.1.4.

The research work presented in this thesis has contributed three solutions:

- developed an integrated framework approach that allows ITS systems to interact with each other and the infrastructure, therefore, minimising the intelligence within the vehicle and moving it to the infrastructure.
- the integrated framework allowed exchange of vehicle messages between the ITS (ISA and dWIM) system and infrastructure. Thus, allowing remote vehicle data (speed and weight) monitoring and control.

- developed a model with stochastic behaviour thus making it suitable in situations where uncertainties between input and output parameters exist. This model uses a GA to optimise the FLS and, therefore, improving traffic performance.
- the traffic improvement algorithm demonstrated improvement in the **average** traffic efficiency in terms of density, flow rate and speed, when applied to real time scenario: Speed improved by 6%, flow rate improved by 2.8% and density by 10%.
- development of a time-to-market predictor model that acts as a guide to indicate the influence of various factors on a new technology launch. The resultant model applied multicriteria analysis methods using a questionnaire and feedback from industry experts and gave an estimated time to market for a new technology.
- The time to market toolkit predicted with accuracy for the following current automotive technologies. Bluetooth prediction accuracy was 99.5%, restraints technology was 87.5%, and pedestrian protection technology was 93.6%.

The physical integration of the systems software applications were developed for handling the message transmission, and the two ITS systems (ISA and dWIM) were integrated physically through the use of a CAN bus as discussed in Nwagboso, Georgakis et al. (2002). The evaluation of the methodology was implemented by the generation of a case study for the development of an integrated safety system.

To enforce speed limits on roads, an intelligent remote speed control system was developed that employs the technologies of Intelligent Transport System that focuses on infrastructure – vehicle – infrastructure communication. An intelligent methodology is needed to integrate the technologies, the driver and the vehicle in order to start to address some of the concerns of deploying the systems. This is discussed in Nwagboso, Rangwala et al. (2004).

In the paper Rangwala, N. (2002), states the importance of integrating enforcement systems as part of ITS systems that illustrate how, successful integration of such systems within vehicle device networks will lead to greater efficiency and better services. Communication amongst these systems and infrastructure can allow the enforcement agencies and vehicle operators/owners to monitor the vehicle continuously.

7.3 Secondary contributions

7.3.1 Beacon based ISA System

Plowden and Hillman, (1996) state that in-vehicle speed limiters have substantial potential for enforcing speed limits. European legislation made its use compulsory since March 1988 on almost all coaches and heavy goods vehicles. Some lorries and coaches are limited to 60mph, but this only addresses top speeds and can, therefore, only enforce the speed limit on motorways. A beacon based ISA system was developed as a part of this research. Comparing this to a GPS based system it is found that the later has a number of advantages and drawbacks (Table 7-1).

System	Benefits	Drawbacks
GPS based VSCS	vehicle manufacturer driven	requires map accuracy weak GPS signal can pose problems in dense areas every change in limit requires a map update does not account for temporary speed limits as this would require frequent map updates unable to manage dynamic sped limits
Beacon based VSCS	low in cost change in the limit can be easily incorporated temporary limits like road works, school time limits can be programmed	Likely to be government led maintenance and initial setup costs

Table 7-1: Comparison of technologies

The above review and a number of similar ones that are discussed in Chapter 2 have led to the selection of this technology (beacon based communication) ISA system. The ISA system is still under research across Europe. The development of this technology is also discussed in a perspective for intelligent trucks in Rangwala et al., (2003).

7.3.2 dWIM system

The dWIM system developed for this research aims to demonstrate the ability of an onboard sensor to monitor the weight of the vehicle when it is in motion and is discussed in Rangwala, N. (2002). Perrett (1996) has indicated in their paper that weighbridges allowing' vehicles to be weighed by driving upon them are significantly expensive, and the results are not particularly accurate.

These results are also limited in terms of enforcement since the vehicles have to be driven to weighbridges. The system described in Chapter 3 demonstrates an onboard sensor concept and describes a method to integrate the system along with other systems on the vehicle. This is done is such a way that it can be used for enforcement applications. Both systems are integrated together along with some simulated vehicle parameters, and the results of tests are specified in Chapter 4.

7.4 Future Research Direction

7.4.1.a *Use wireless instead of wired channels for communication.*

Section 2.5 has reviewed various short and long range technologies that can be used for automotive applications. By using a wireless mode of communications, the proposed framework brings the vehicle, ITS systems and the infrastructure together.

The first is a long range application where the enforcement authority monitors the vehicle from a remote site. In this case, the use of LEOS technology is the best solution, given the data exchange rate and coverage.

Using LEOS communication, data exchange is done via the subscriber equipment that can be connected to the in-vehicle enforcement systems and computer systems at remote enforcement authorities.

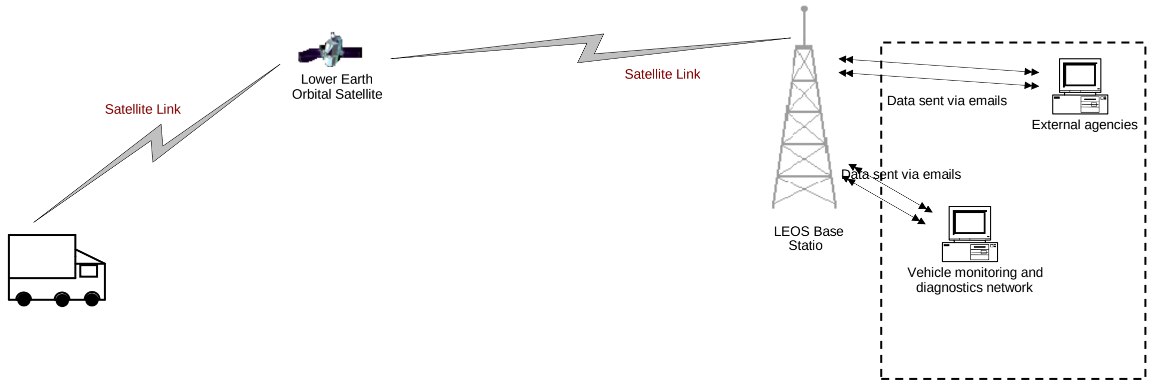


Figure 7-1: LEOS based communication

The other application is a short range scenario where the enforcer is within a short distance (for example up to 100m) of the vehicle requesting information. In this case, Bluetooth can be used as a communication technology. In the other instance, Bluetooth offers short range communication where Bluetooth transceiver modules are connected to the vehicle's network (and in-vehicle enforcement systems) and law enforcing system (infrastructure within 100 meters from the vehicle).

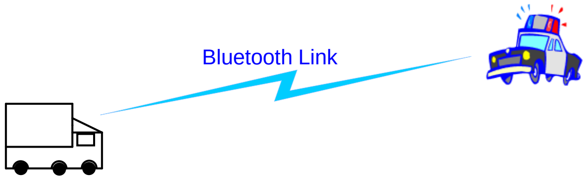


Figure 7-2: Bluetooth based communication

The model and systems discussed in this report form a basis for some future ITS systems.

7.4.2 Traffic Improvement Algorithm

The TIA is an application of the proposed architecture. It was also intended to validate it by employing simulation tools to create a traffic scenario where the proposed algorithm and FLS improve the performance when used (section 5.4). Whilst the immediate objective is achieved using the TIA, this model can be further improved by applying further training scenarios to it.

The model demonstrated satisfactory performance in reducing the travel time on the simulated network. Future research can evaluate its performance when other fitness parameters (for example, vehicle emissions) are used.

7.4.3 Time to market model development

The toolkit discussed and developed in this research used types of multi criteria analysis methods. It employed a formulated questionnaire that acted as a method for input from industry experts and then used this to determine the estimated time. The functionality of the toolkit was tested for validity by applying it to existing and under research technologies. The results obtained from these tests indicated that the model is practical, but by using other multicriteria methods and / or different feedback tool this model can be further developed.

This toolkit initiates the concept of using multicriteria analysis together with industrial experiences and was able to demonstrate a time to market analysis. Using the appropriate influencing factors, the toolkit helps to determine the time a new technology can be brought into the market. The conclusion from the application of the toolkit was that it could provide a robust analysis tool for developers in various industries.

7.5 Final Remark

Development of ITS systems is increasing rapidly across Europe and the rest of the world. With the growth in system complexity, the requirement for higher computational power is also increasing. Enforcement systems developed and discussed in the thesis help to visualise and support the framework that would benefit the automotive industry.

The research also proposed a novel traffic improvement algorithm that can be implemented in the real world through the developed framework. Finally, a toolkit was presented that can predict time-to-market for a new technology or concept to reach the end-user.

Chapter 7: Conclusions and Further Work

The proposed architecture, traffic improvement algorithm and time-to-market toolkit offer, ITS applications and future research opportunities.

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